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CONSIDERATION OF INITIAL NUCLEAR RADIATION IN AN ATTACK ON A CIVILIAN POPULATION

By: BURT R. GASTEN

Prepared for:

NATIONAL BUREAU OF STANDARDS
U.S. DEPARTMENT OF COMMERCE
WASHINGTON, D.C. 20234

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

For megaton-yield weapons, the primary prompt casualty producing effect is blast. Hence, in the past, when the most likely attack on a large city was by large weapons, most studies undertaken failed to include the effects of initial nuclear radiation (INR). However, → next page

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20 ABSTRACT (Continued)

current attack studies must include the likelihood of smaller-yield weapons, those of the order of tens of kilotons, and therefore, INR must be considered. This study was undertaken to examine the casualties resulting from INR in addition to those caused by blast. The ANDANTE computer model, maintained by the Federal Emergency Management Agency (formerly Defense Civil Preparedness Agency), was used in this study.

Graphs were developed that demonstrated the protection against initial nuclear radiation, the initial protection factor, that would limit the increase in deaths due to the inclusion of radiation to given percentages over that resulting only from blast as a function of the blast protection of the population. It was confirmed that radiation protection becomes very important for attacks by low-yield weapons. For 5-kt weapons, radiation protection was needed to limit additional deaths to 10% when shelters were such that half of the population or less would be fatally injured when overpressures exceeded 7.5 psi. For 40-kt weapon attacks, radiation protection was needed when shelters protected 50% or more of the population against 11 psi or greater. Radiation protection was needed for 15-psi or stronger shelters for attacks by weapons with 200-kt yields, and for 25 psi or stronger shelters for 1-Mt weapons.

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IN MEMORIAM

Dr. Burt Gasten, who was principal investigator on this study died suddenly after having completed the draft of this report. His colleagues had the sad duty to see the report through its final phases. It is hoped that the results do honor to his professional competence and his high standards.

ACKNOWLEDGEMENTS

The author wishes to acknowledge the aid and assistance provided by Dr. Lewis Spencer, National Bureau of Standards, the contract monitor for this project. The author also received valuable assistance and data from Dr. Charles M. Eisenhauer, NBS, Dr. Leo Schmidt, Institute for Defense Analysis, and Messrs. David Benson and George Sisson of the Defense Civil Preparedness Agency. Mr. Jerry Backman of the Defense Civil Preparedness Agency Computer Center was extremely helpful and cooperative in advising the author of the input requirements for running the computer problems, as well as in doing the actual computer-related work.

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I INTRODUCTION

In the 1960s when the Defense Civil Preparedness Agency (DCPA) (now incorporated into the Federal Emergency Management Agency (FEMA)) was sponsoring studies of the effects of nuclear weapon attacks on civilian populations, megaton weapons* were the primary threat that required examination. With these weapons, the initial nuclear radiation (INR) emitted within the first minute after explosion is a minor threat when compared to the effects of blast.

However, with the advent of multiple reentry vehicles, it became necessary to include lower-yield weapons in the threat to civilian populations. With smaller weapon yields, INR becomes a more significant death or injury producing mechanism at given levels of peak overpressure.

Failure to address the relation between radiation and blast protection requirements in the design of shelters could lead to ineffective protection of the civilian population, or it could escalate the cost of providing a given level of protection for that population.

If many identical weapons should be targeted on a city, the primary casualty-producing effect of blast would accrue only from the closest weapon, that producing the highest peak overpressure. However, the effects of prompt radiation would be additive, and therefore might produce casualties not occurring in the absence of INR.

This study was undertaken to examine the casualties from both initial nuclear radiation and blast on a civilian population for a variety of hypothetical attacks on an American city. Although Detroit was the city used for the study, the results are sufficiently general that they can be applied to any large population group.

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*Nuclear weapon yields are often measured in terms of the weight of TNT that would produce an equal amount of explosive energy. A 1-kt nuclear weapon releases 4.183 terajoules (4.183×10^{12} joules) of energy. The energy released after about one second is not included in the nuclear weapon yield.

II BACKGROUND

A. Energy Partition

When nuclear weapons are used in an attack on a populated area, casualties may result from the effects of one of many phenomena of nuclear explosions, as well as from the combined effects of several of the phenomena. Phenomena that occur promptly are air blast and ground shock, thermal radiation and heat, initial nuclear radiation, and electromagnetic pulses. Following these initial phenomena is the residual radiation from the decaying nuclides in nuclear weapon fallout and neutron-activated materials.

Nuclear weapons develop energy by either (or both) of two general mechanisms--fission or fusion. For fission weapons, the energy results from the fissioning or breakup of heavy isotopes, U^{235} or U^{238}, or Pu^{239}. For fusion weapons, the energy generated is released when hydrogen and other light isotopes are combined to make up helium. Generally, thermonuclear weapons utilize both fusion and fission reactions.

For a fission weapon, approximately 85% of the explosive energy produces air blast, shock, thermal radiation, and heat. Five percent of the energy partitions to the nuclear radiation released within a minute or so of the explosion (the so-called initial nuclear radiation), and the remaining 10% is the residual or delayed nuclear radiation emitted after about one minute. In a thermonuclear (fusion) weapon, the residual radiation fraction may drop to about 5%. The residual radiation is largely due to the radioactivity of the fission products present in the weapon debris. The initial nuclear radiation consists primarily of gamma rays and neutrons, which can penetrate great distances through air and considerable distances through solids or liquids.

This study examines the combined effects on a population of two of the prompt phenomena of a nuclear weapon explosion--blast and initial nuclear radiation.

B. Blast Phenomena

A nuclear weapon exploding above the ground produces a shock front that progresses outward approximately spherically until the earth is encountered. The part of the spherical wave that strikes the earth is reflected upward, but does so into air that has already been heated and compressed by the passage of the incident wave. Hence, the reflected wave front moves with a higher velocity than the incident wave front, and near the ground overtakes and merges with the incident wave, forming what is called the Mach stem.[1*] Figure 1 shows the outward motion of the blast wave near the earth's surface in the Mach region. The surface labeled "path of the triple point" separates the region of regular reflection from the region of irregular, or "Mach" reflection.

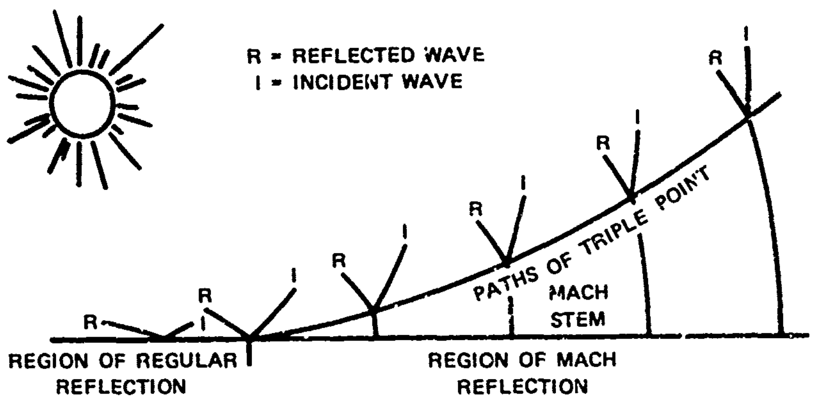

FIGURE 1 OUTWARD MOTION OF THE BLAST WAVE NEAR THE SURFACE IN THE MACH REGION

The magnitude of the peak overpressure resulting from a nuclear explosion has been determined from the atmospheric nuclear tests of the 1950s and 1960s, and from analytic studies. Figures 2 and 3 show the peak overpressure on the ground from a 1-kt explosion as a function of distance from ground zero (that point on the earth directly below the weapon) and the height of burst of the weapon. The height of burst and ground range that results in a peak overpressure may be scaled for other weapon yields by using the scaling rule

*References are listed at the end of this report.

$$\frac{d}{d_1} = \frac{h}{h_1} = W^{1/3}$$

where d_1 and h_1 are the distance from ground zero and the height of burst of a 1-kt weapon for a given peak overpressure (given in Figures 2 and 3), and d and h are the corresponding distances for a weapon of yield W kt. Hence, if a given peak overpressure occurs for a height of burst and ground range, h_1 and d_1, for a 1-kt weapon, it will occur for $h = 2.15h_1$ and $d = 2.15d_1$ for a 10-kt weapon, for $h = 4.64h_1$ and $d = 4.64d_1$ for a 100-kt weapon, for $h = 10h_1$ and $d = 10d_1$ for a 1 Mt weapon, and for $h = 21.5h_1$ and $d = 21.5d_1$ for a 10-Mt weapon.

C. Initial Nuclear Radiation

The nuclear radiation emitted from an exploding nuclear weapon consists of gamma rays, neutrons, beta particles, and a small amount of alpha particles. Most of the neutrons are emitted by the fission and fusion reactions during the first microsecond of the explosion. Part of the gamma rays are emitted simultaneously with the explosion. The remainder of the gamma rays are produced by secondary nuclear processes, such as from decay or de-excitation of fission products and by secondary scattering or neutron capture reactions such as by nitrogen. Alpha particles result from normal radioactive decay and from fusion reactions. Beta particles are produced from fission product decay.

The range of penetration in air of the alpha and beta particles is sufficiently short that their effect on people is small compared to that of neutrons, gamma rays, or blast. Similarly, X-rays emitted by the explosion or the hot debris have a sufficiently short range that they do not constitute an injury hazard when compared to the other phenomena.

Figure 4 shows the calculated time dependence of the gamma ray energy output per kiloton energy yield from a hypothetical nuclear explosion in air, and indicates the relative intensities and source mechanisms of the gamma rays.[1,2]

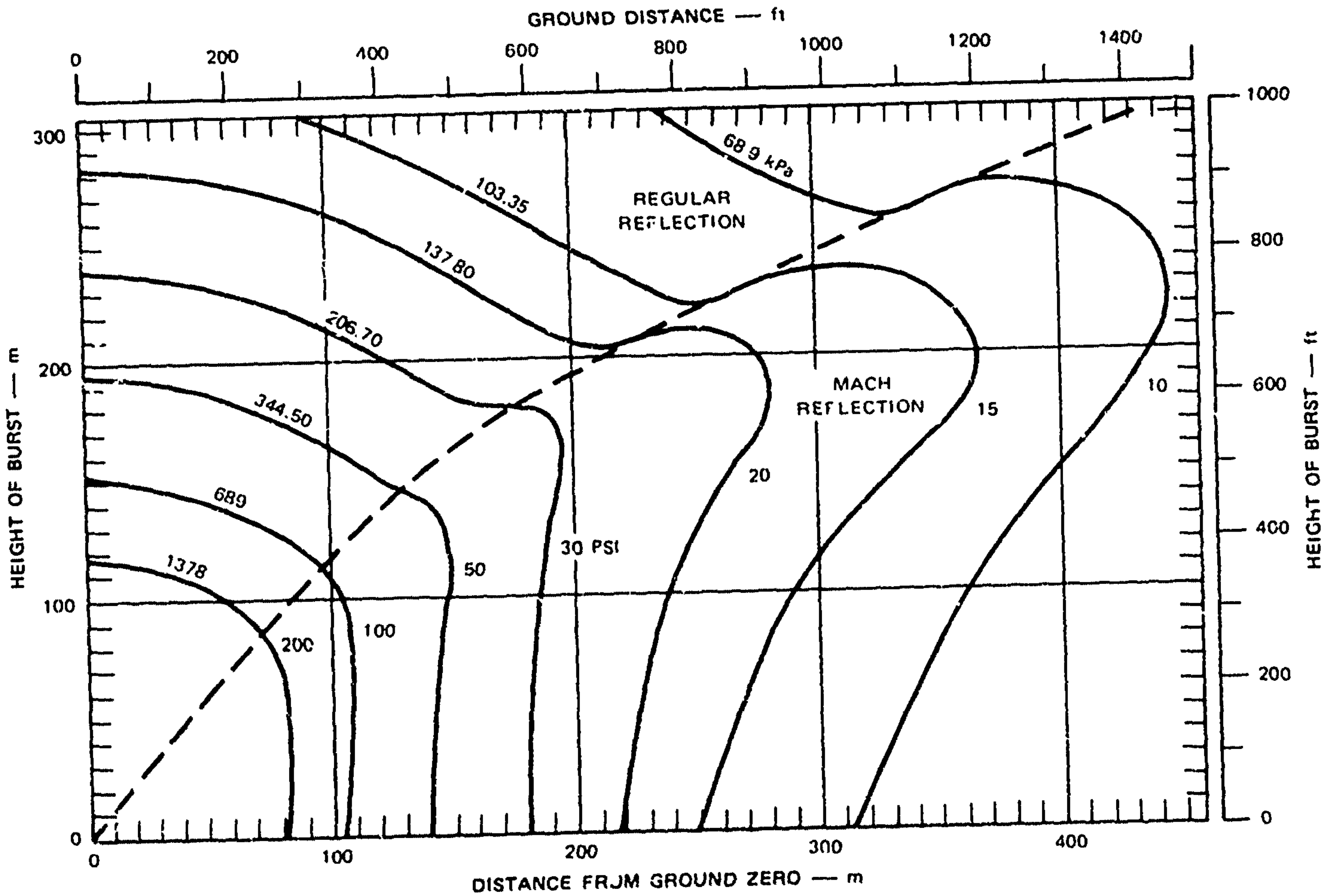

FIGURE 2 PEAK OVERPRESSURES ON THE GROUND FOR A 1-kt BURST (intermediate-pressure range)

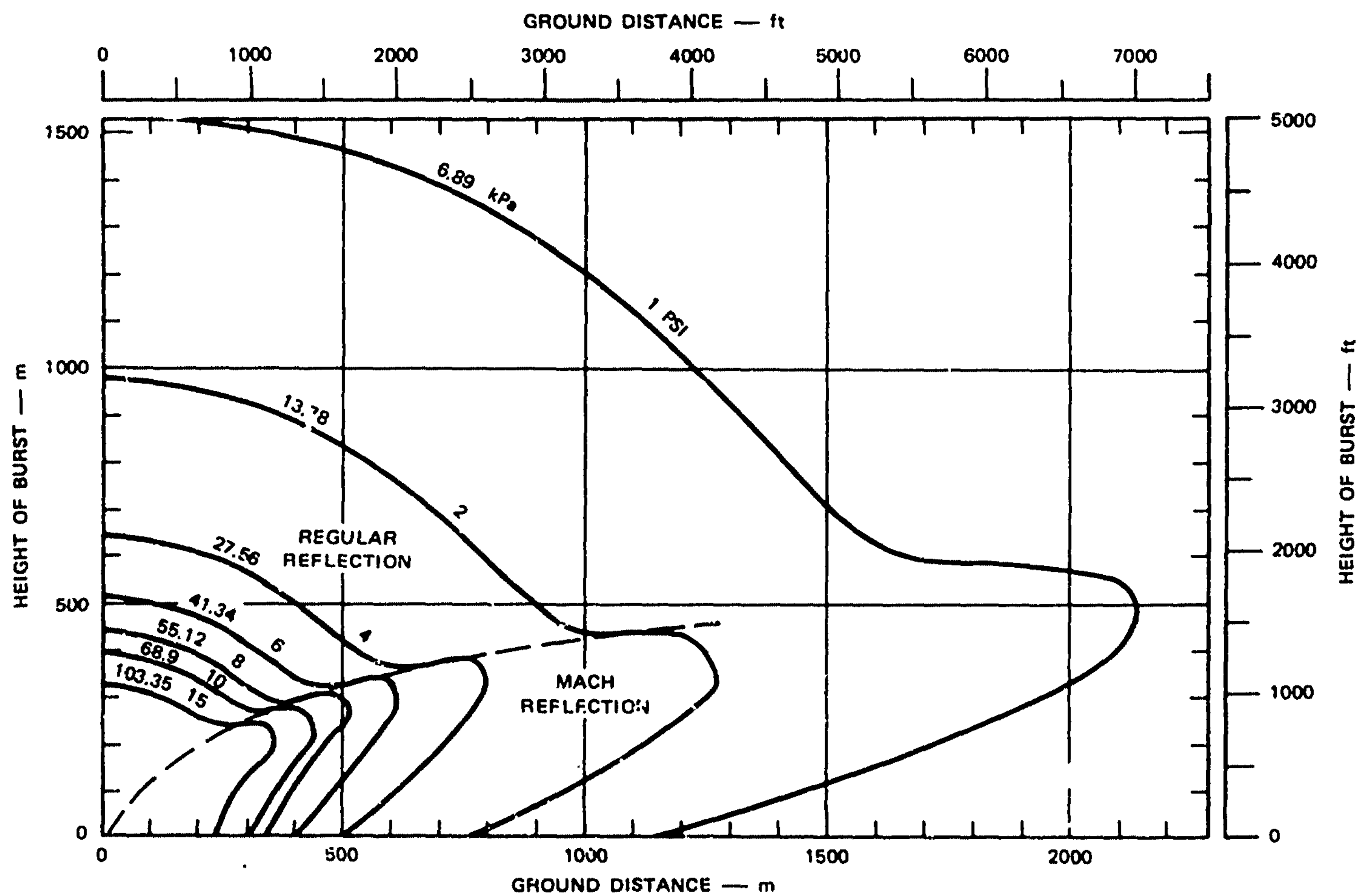

FIGURE 3 PEAK OVERPRESSURES ON THE GROUND FOR 1-kt BURST (low-pressure range)

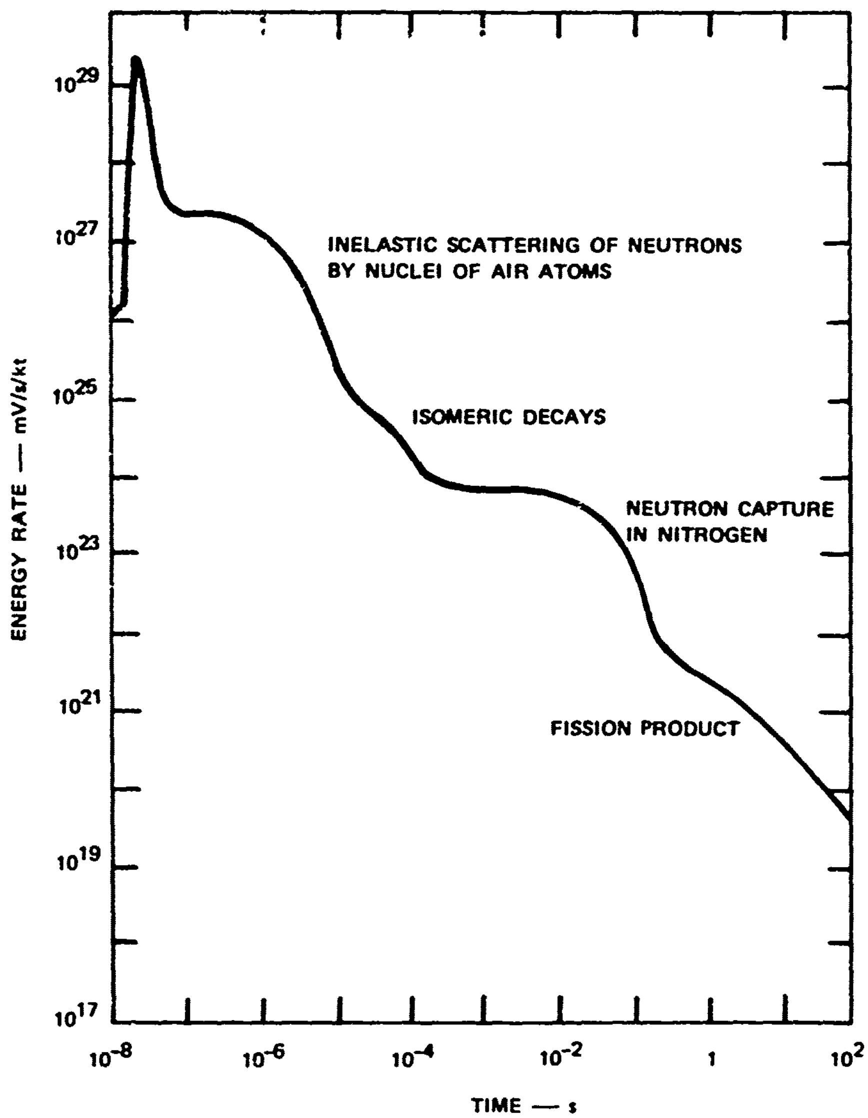

FIGURE 4 CALCULATED TIME DEPENDENCE OF THE GAMMA-RAY ENERGY OUTPUT PER kt ENERGY YIELD FROM A HYPOTHETICAL NUCLEAR EXPLOSION

Figure 5 shows the estimated gamma ray dose in rads (tissue) near the ground from a fission weapon as a function of weapon yield and slant range. Figure 6 shows the gamma dose that would result from a thermonuclear weapon of 50% fission yield. For these figures, the air density was taken to be 0.9 that of normal sea-level density. Comparison of the slant ranges corresponding to radiation doses at 100 kt shows that fission weapons produce higher doses than fusion weapons at the same ranges.

Neutrons produced by nuclear explosions have energies ranging up to 14 MeV, and although they make up only about 1% of the energy released in a typical weapon, they penetrate considerable distances in air and contribute greatly to the hazard.

The neutron output spectrum from a fission weapon is shown in Figure 7 as a solid line. That from a thermonuclear weapon (50% fission) is shown as the dashed line. Significant in the comparison of the two spectra is the presence of 14-MeV neutrons in the thermonuclear output spectrum. As the neutrons are transported through air, elastic and inelastic scattering causes the spectrum to develop comparatively larger components at lower energies.

Figure 8 shows the neutron dose that would be received at various slant ranges as a function of weapon yield of a fission weapon. Figure 9 shows the dose for thermonuclear weapons. These curves include the effects of distance, as well as the effects of scattering and capture.

Initial radiation is a more significant injury mechanism compared to blast for small-yield weapons than for large, as is well demonstrated in Figure 10, which is taken from Ref. 3. The figure shows that the radiation dose remains high at a given distance as the weapon yield is decreased, while the peak overpressure decreases more rapidly.

D. Thermal and Residual Nuclear Radiation

The thermal radiation emitted as a result of a nuclear explosion makes up a large fraction--35% to 45%--of the total energy released. In this study, however, the population is assumed to be protected from thermal radiation by walls, clothing, or shadowing.

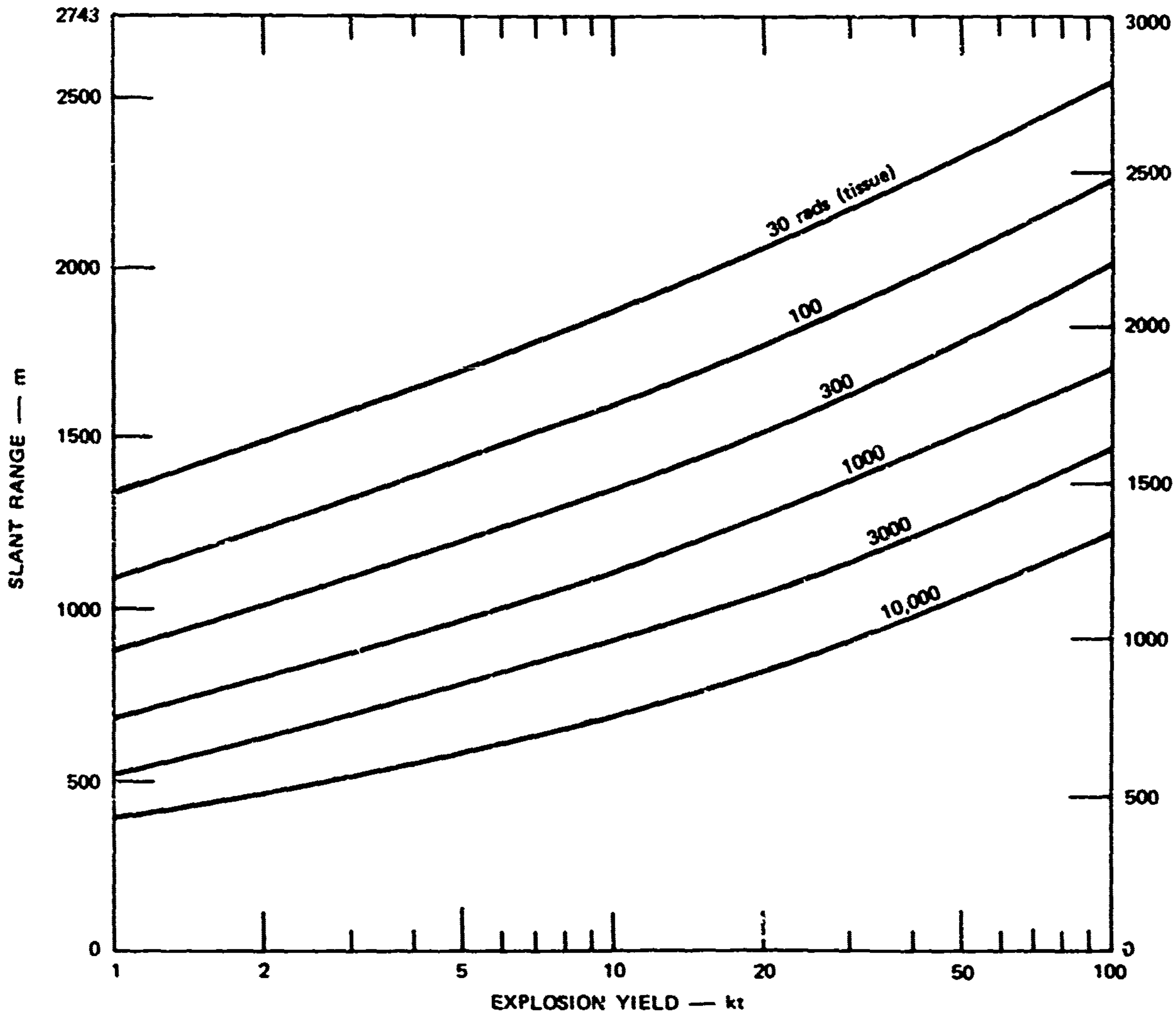

FIGURE 5 SLANT RANGES FOR SPECIFIED GAMMA-RAY DOSES FOR TARGETS NEAR THE GROUND AS A FUNCTION OF ENERGY YIELD OF AIR-BURST FISSION WEAPONS, BASED ON 0.9 SEA-LEVEL AIR DENSITY. (Reliability factor from 0.5 to 2 for most fission weapons.)

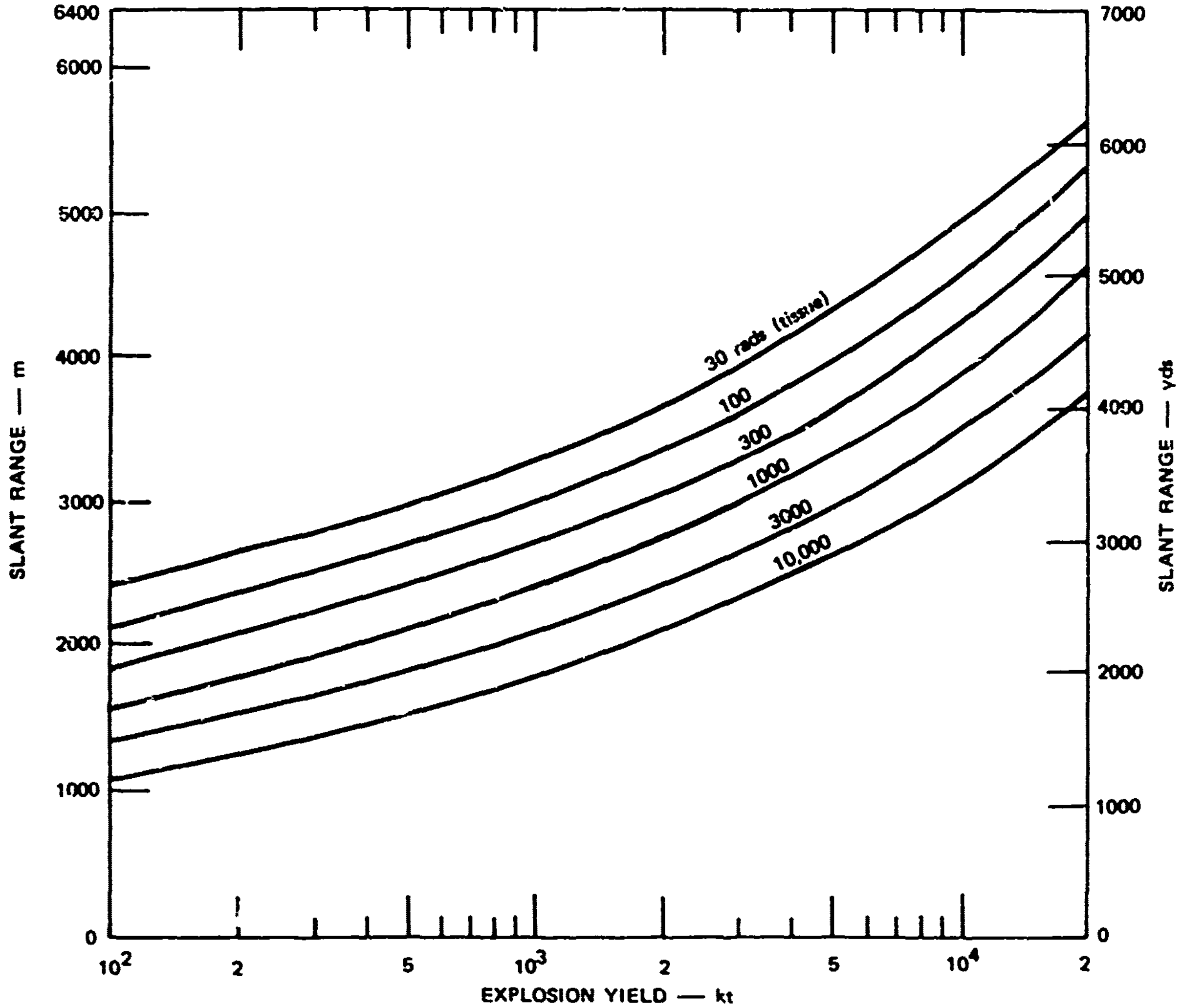

FIGURE 6 SLANT RANGES FOR SPECIFIED GAMMA-RAY DOSES FOR TARGETS NEAR THE GROUND AS A FUNCTION OF ENERGY YIELD OF AIR-BURST THERMONUCLEAR WEAPONS WITH 50 PERCENT FISSION YIELD, BASED ON 0.9 SEA-LEVEL AIR DENSITY. (Reliability factor from 0.25 to 1.5 for most thermonuclear weapons.)

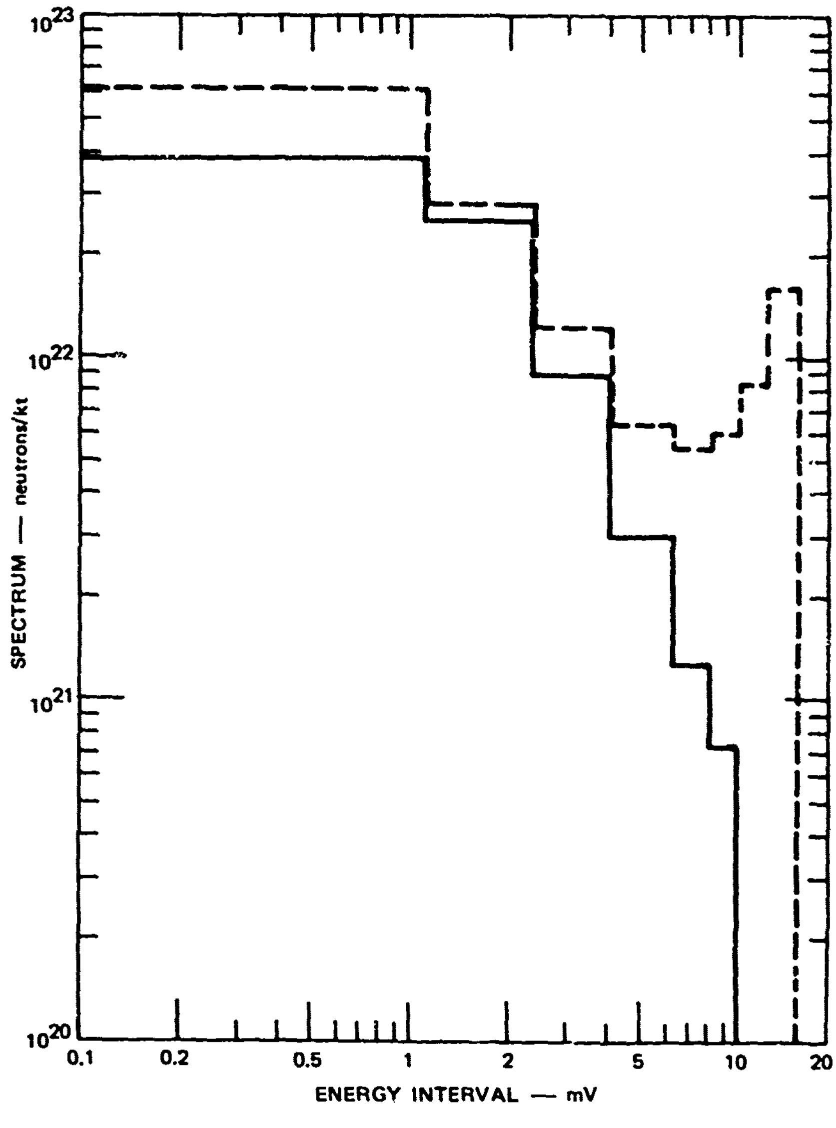

FIGURE 7 NEUTRON SPECTRUMS FOR A FISSION WEAPON (solid) AND FOR A THERMONUCLEAR WEAPON (dashed) PER kt OF TOTAL ENERGY YIELD

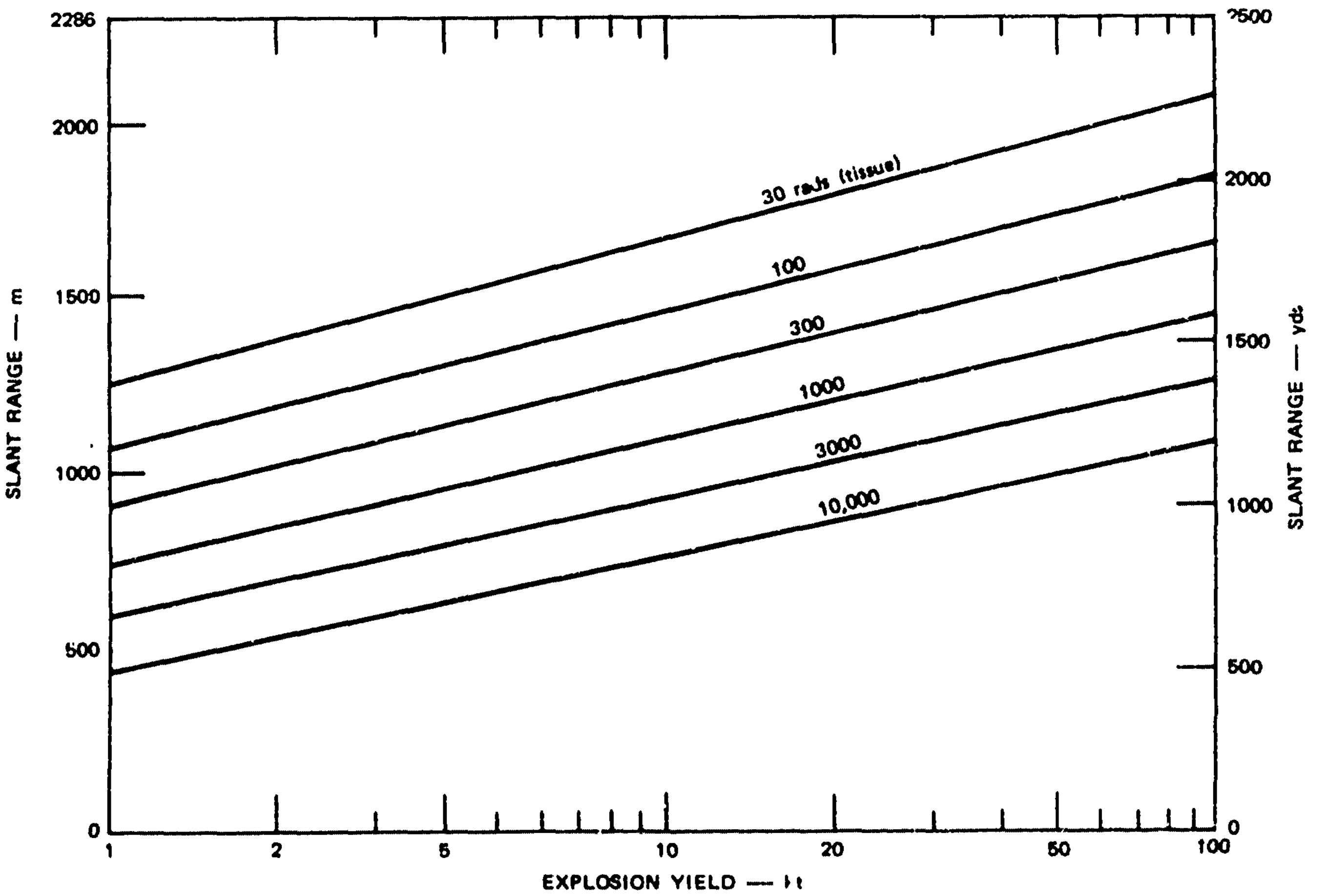

FIGURE 8 SLANT RANGES FOR SPECIFIED NEUTRON DOSES FOR TARGETS NEAR THE GROUND AS A FUNCTION OF ENERGY YEILD OF AIR-BURST FISSION WEAPONS, BASED ON 0.9 SEA-LEVEL AIR DENSITY. (Reliability factor from 0.5 to 2 for most fission weapons.)

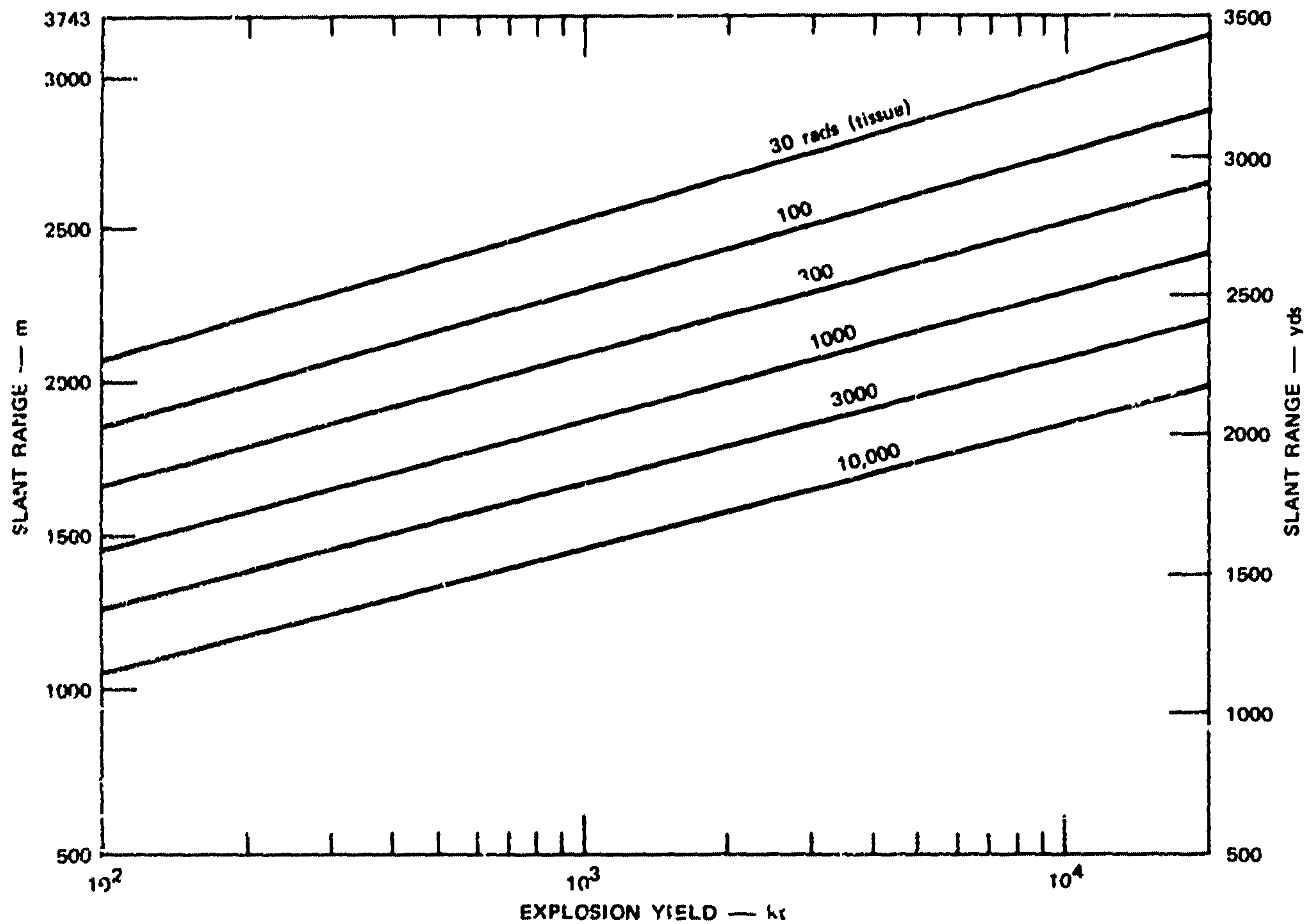

FIGURE 9 SLANT RANGES FOR SPECIFIED NEUTRON DOSES FOR TARGETS NEAR THE GROUND AS A FUNCTION OF ENERGY YIELD OF AIR-BURST THERMONUCLEAR WEAPONS BASED ON 0.9 SEA-LEVEL AIR DENSITY. (Reliability factor 0.15 to 1.5 for most thermonuclear weapons.)

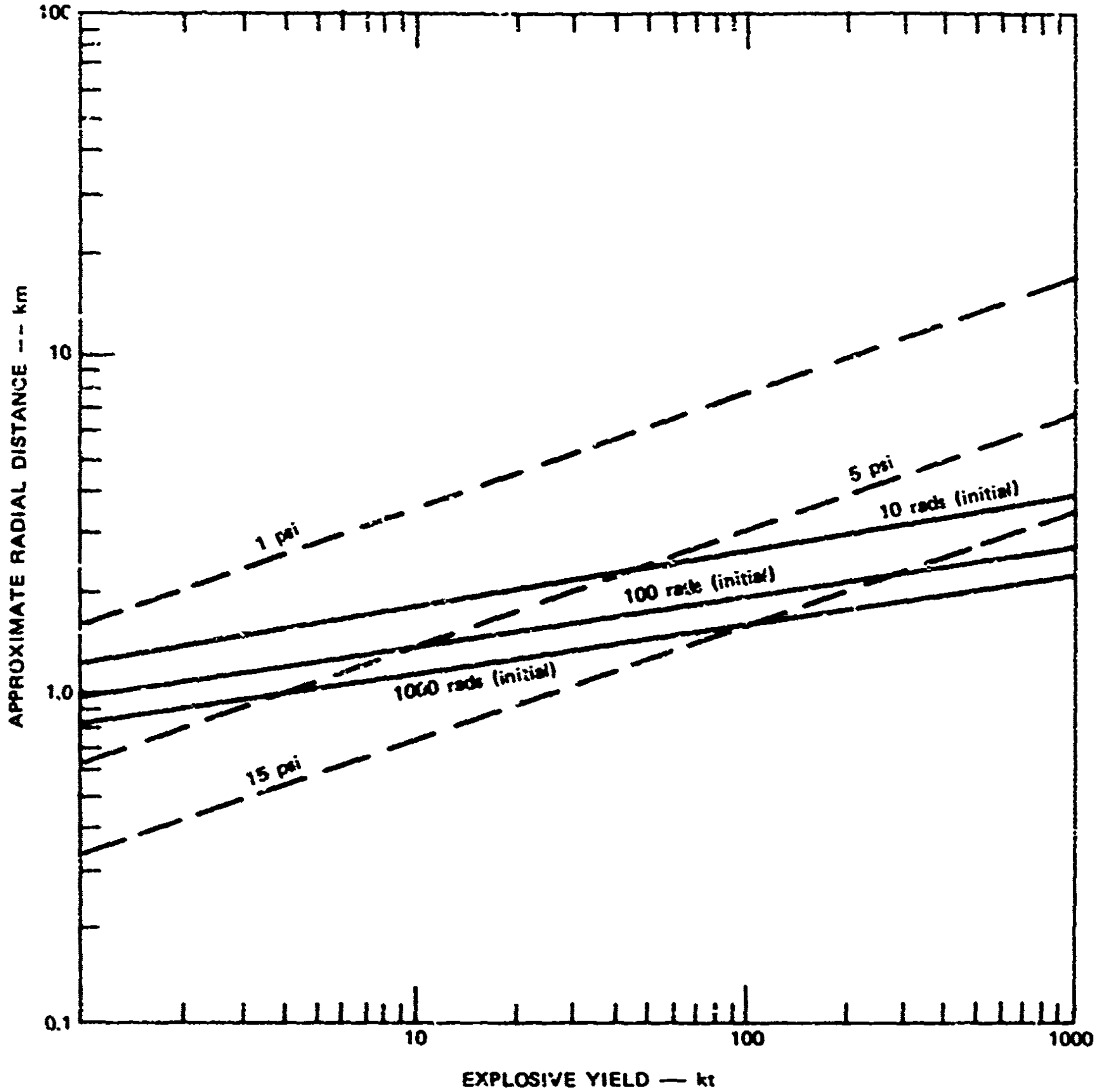

FIGURE 10 NUCLEAR EXPLOSION IN AIR: COMPARISON OF DISTANCE AND EXPLOSIVE YIELD FOR BLAST, THERMAL RADIATION, AND COMPONENTS OF THE INITIAL NUCLEAR RADIATION FIELD

Similarly, the effects of residual nuclear radiation, including fallout from a nuclear weapon, are not part of this study. It is presumed that if the weapon explodes at an altitude low enough that fallout occurs, the exposed population will reach shelter prior to exposure to fallout-generated radiation.

E. Blast Casualties

The injuries from blast are generally defined in terms of blast peak overpressure, although dynamic pressure may be the actual mechanism for injuring or killing a victim. This convention results from the fact that there is a direct relationship, under ideal conditions, between the two pressures[1]--viz:

$$q = 5p^2/2\ (7\ P_0 + p)$$

where q is the peak dynamic pressure, p is the peak overpressure, and P_0 is the ambient pressure prior to passage of the blast wave.

Blast-induced injuries will result from victims being thrown about and impacting on hard surfaces. In addition, the blast wind will throw objects about, to lethal or injurious speeds. In strong structures, such as basements without windows below a full slab floor, the primary injury mechanism would be produced by the breakup and collapse of the overhead floor. Injuries from the direct effects of excessive overpressure on the body can be ignored by comparison with those resulting from the victims being thrown about or being struck by flying debris.

A great deal of study of blast-induced injuries has been done for various types of structures and for locations within the structures.[4-8] These studies have examined representative structures among shelter locations that have been identified in the United States. Although this work by Longinow et al. has been done for specific structures, their results have been combined into groups of various types of shelters categorized by their "hardness"--i.e., the degree of blast protection afforded to their occupants, as reported by Bensen and Sisson.[9,10] The

casualty data can be characterized by the median lethal overpressures (MLOP) and median injury overpressures (MIOP) and a standard deviation. Figure 11 is a representative curve showing peak overpressure as a function of number of persons killed or injured for a typical basement of a wood frame structure (shelter category D). For this category, the MLOP is taken as 10 psi and the MIOP at 4 psi.

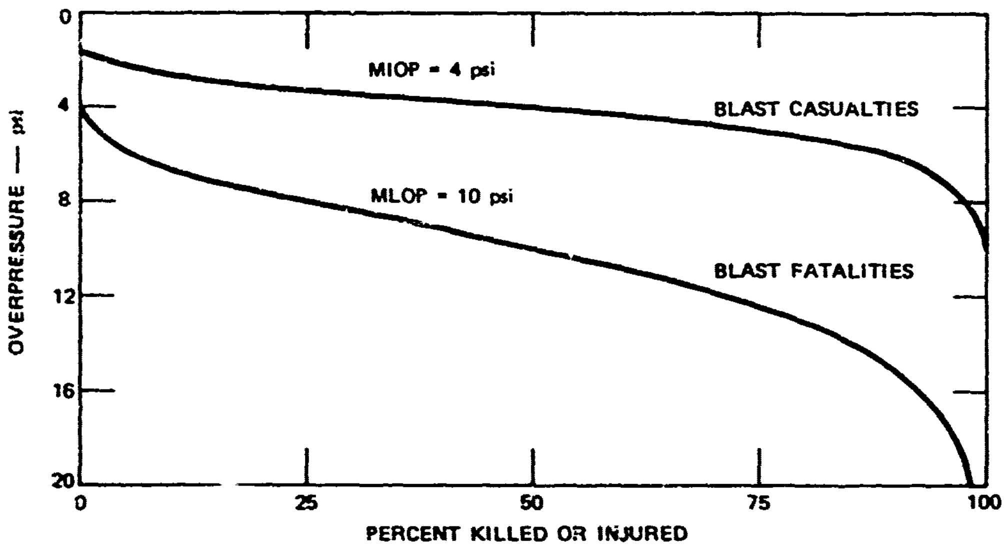

FIGURE 11 OVERPRESSURE vs. PERCENT KILLED OR INJURED--BASEMENT OF WOOD FRAME STRUCTURES (NSS shelter category D)

A correlation of the categories with actual structures is shown in Table 1. This table is by no means complete, and the reader is referred to References 9 and 11.

An additional category of heavy shelters with an MLOP of 55 psi and an MIOP of 45 psi was included in this study. The blast vulnerability functions--lethality or injury--have been approximated by the cumulative log-normal function,

$$I = \frac{1}{\sqrt{2\pi}} \int_0^p dp' \, \frac{e^{-\frac{1}{2}\left[\frac{\log p' - \log p_o}{\sigma \log p_o}\right]^2}}{p' \, \sigma \log p_o} \qquad (1)$$

Table 1

BLAST VULNERABILITIES OF VARIOUS STRUCTURES

Category	Structure	MLOP (psi)	MIOP (psi)
A	Mines, caves, tunnels	35	25
B/C	Best basements	10	7
D	Basement (frame building)	10	4
E/F	Upper stories (strong walled buildings)	8	2
--	Unwarned	4	2

where I is the fraction of the total population killed or injured, p is the overpressure to which the population is exposed, p_o is the median lethal (or injury) overpressure, and σ is the standard deviation.* As defined, this function equals 0.5 for $p = p_o$ and 1.0 for $p \to \infty$.

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*In many DCPA computations, the log-normal function is replaced by an approximation,[10]

$$I = 1 - e^{-Kp^E} \tag{2}$$

where K and E are suitable constants. The values of the standard deviations appropriate to each median lethal (or median injury) overpressure [for use in Eq. (1)] were obtained by the relationship

$$\sigma \ln p_o = 1.132/E . \tag{3}$$

The constant 1.132 was determined by graphical comparison of the two functions for I. K is related to the MLOP or MIOP by the approximation

$$p_o = \left[\frac{0.69315}{K}\right]^{1/E} . \tag{4}$$

Data were supplied in the form of the constants K and E.[9] This correlation was needed to obtain the σs and p_os for use with Eq. (1).

Table 2 relates the values of the p_os with corresponding standard deviations. These were determined from the values of E and K supplied by DCPA.[10]

Table 2

STANDARD DEVIATIONS ASSOCIATED WITH MLOPS AND MIOPS

p_o	σ
2 psi	0.4666
4	0.2333
7	0.1662
10	0.1405
14	0.07149
15	0.06967
25	0.05861
35	0.05307
45	0.02703
55	0.02568

F. Initial Nuclear Radiation Casualties

In humans, the minimum nuclear radiation level above which symptoms of radiation effects can be noted within weeks in an individual is taken as about 50 rads (tissue). The symptoms of radiation sickness include headache, dizziness, malaise, abnormal sensations of taste and smell, nausea, vomiting, diarrhea, decrease in blood pressure, decrease in white blood cells and blood platelets, increased irritability, and insomnia. The largest exposure that does not cause illness requiring medical care for the majority of the population is about 200 rads. The latter exposure is believed to be that where death is first noted (within several weeks) for some of those exposed.[11-13]

A value of 450 rad has been estimated as the median lethal dose since 1949. Some studies made more recently indicate that a lesser dose--perhaps 400 rad--might be valid, while others estimate a higher one. Noteworthy is that these numbers are for heterogeneous populations. The old, the young, or the ill might succumb at perhaps 50 to 100 rad less, while the remaining population might survive a somewhat greater exposure.[13]

For this study, three levels of radiation exposure were chosen--50 rad, 200 rad, and 450 rad. Few data are available on radiation of humans leading to early injury or death; and distribution functions of the exposed population succumbing to sickness or death as a function of radiation have not been well established. Therefore, rather than estimate a distribution function, the population is separated into four groups--those exposed to less than 50 rad ("unaffected"), those exposed to between 50 and 200 rad ("ill"),* those exposed to between 200 and 450 rad ("seriously ill"),* and those exposed to more than 450 rad ("dead"). It should be noted that in actuality many of those in the "seriously ill" range will die, and presumably many of those exposed to doses of 450 rad or more will survive.†[11]

The radiation criteria used here must be accepted as approximate,[13] and the effects as short term--i.e., within a few months. Long-term effects such as reduced fertility, cataracts, leukemia, other cancers, and life shortening and accelerated aging also will occur over a period of years for some of those exposed to doses below 50 rad.

G. Combined Effects

Because radiation exposure can cause a decrease in the functioning of the immunity mechanism of the human body, combined injuries--exposure to sufficient radiation as well as mechanical injuries to the body--will

*DCPA (Ref. 11) defines these as "Level I Sickness" and "Level II Sickness."

†Further, adequate medical care cannot be assured for seriously exposed individuals.

often be more severe than the effects taken separately. The number of deaths would be increased due to such "synergistic" effects, and injuries that would have been minor without radiation exposure would frequently become severe. Tests with animals clearly show the presence of synergy for both early and delayed mortality.[1]

Unfortunately, insufficient data exist to numerically establish the synergy between blast and radiation exposures. Therefore, in this study only the total number of persons doubly affected will be reported, with no indication of the fraction of the injured that will die of combined effects.

H. Initial Nuclear Radiation Protection Factors

An unprotected person would be exposed to the free-field radiation dose resulting from a nuclear explosion. Above grade, inside a typical building at the same distance from the burst, the dose may decrease by a factor of one to five. This factor is defined as the initial radiation protection factor (IPF). In the basement of a wood frame building, the IPF might be 4 to 10, whereas the IPF in a basement of a large, heavily constructed structure, with a massive concrete floor system over the basement, may range from 10 to 100. Sub-basements may have IPFs in the range of 100 to 1000. Subway stations, tunnels, mines, and caves are reported to have IPFs ranging from 10 to 1000.[11] One foot of unbroken dirt will provide an IPF of about 10. Calculations of attenuation factors (reciprocal IPFs) for elementary barriers have been reported by Spencer,[14] for initial gamma rays.

In the study reported here, the IPFs were taken as an independent variable, rather than one correlated simply to the median lethal (or median injury) overpressure. Strengthening a structure to increase survivability to blast would not necessarily result in a corresponding increase of the protection factor for initial radiation. Hence, shelters must be assessed separately for their protection against blast and against initial radiation.

III COMPUTER MODEL AND ASSUMPTIONS

This study used a computer program, ANDANTE, that is maintained by FEMA at their computer center in Olney, Maryland. This program, prepared by Dr. Leo Schmidt of the Institute for Defense Analysis[15,16] simulates a multiweapon nuclear attack on a city, taking into consideration the population distribution, the location of the weapons, and the effects of blast, initial nuclear radiation, and thermal exposure. ANDANTE is discussed in greater detail in Appendix A.

Hypothetical attacks on the greater Detroit area were examined. The population distribution was based on census data for 1970 extrapolated to 1975. The total population considered was about 3,900,000. Figure 12 illustrates a density distribution map of the Detroit area, with each dot representing about 1500 persons.

Weapon variables in the ANDANTE program include yield, number of weapons, and height of burst. Yields examined were 5 kt, 40 kt, 200 kt, and 1 Mt. Heights of burst were 300 m and the altitude for each weapon yield that maximized the area exposed to more than 10 psi. Table 3 shows the latter, the 10-psi optimized heights of burst, for various yields. It also shows the heights above which no fallout will occur. The computer program determines the laydown pattern of nuclear weapons of the specified yield and height of burst so as to maximize the number of fatalities for a chosen median lethal overpressure (MLOP) protection.

Table 3

HEIGHTS OF BURST FOR 10-psi-OPTIMIZED WEAPONS AND MINIMUM HEIGHT FOR NO FALLOUT PRODUCTION

W	$H_{10\ psi\text{-}opt}$	$h_{min\ fallout}$
5 kt	381 m	104 m
40	761	240
200	1301	457
1000	2225	870

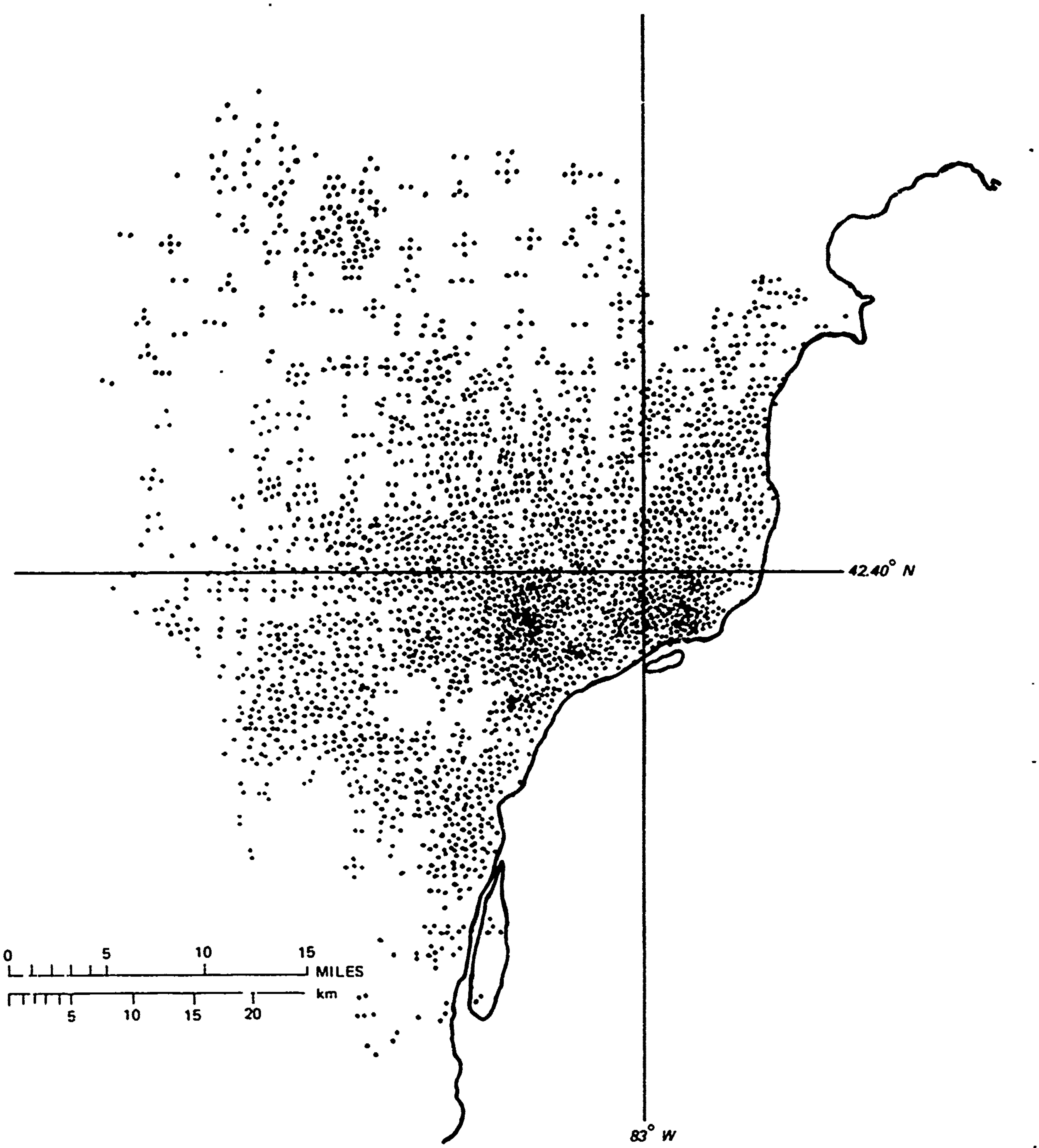

FIGURE 12 POPULATION DENSITY MAP FOR DETROIT AREA

The weapon type chosen for most of the runs was a 100% fission weapon, which produced a greater amount of initial radiation than would a similar yield with a smaller fission component. Some calculations were done of a 50% fission weapon to confirm that casualties would be less, and additional calculations were also made from a hypothetical enhanced-radiation low-yield weapon.

The computer program determines the overpressures and radiation levels to which the population are exposed by curve fits to the data. The procedure is discussed in Appendix A. The initial protection factor, IPF, was varied as an input parameter to determine the increases in casualties over that due to blast only.

IV RESULTS AND DISCUSSION

Attacks by nuclear weapons with several yields were examined in this study. These were 5 kt,* 40 kt, 200 kt, 1 Mt, and 5 Mt, located at altitudes of 300 m and the 10-psi-optimized height. Up to 199 weapons were involved in each attack simulation. As discussed in Appendix A, a subroutine of the ANDANTE computer code optimized the targeting of the weapons based on blast fatalities only.†

Figure 13(a) shows the target locations for 10-psi-optimized target points for 40-kt yield weapons, and Figure 13(b) for weapons exploding at 300 m altitude. The first thirty weapons are shown.

Fatalities that result from an attack of 40-kt weapons at the 10-psi-optimized altitude, as a function of number of weapons, are shown on Figure 14 for a MLOP of 10 psi and a MIOP of 7 psi. This degree of protection is that afforded by best basements (Table 1). Shown are the fatalities due to blast alone, the incremental increase in fatalities due to initial nuclear radiation, and the synergistic increment (the number of persons exposed to greater than 50 and less than 450 rad, who were injured by blast but not killed by it). Also shown is the total number of casualties--i.e., killed or injured by blast and/or radiation.

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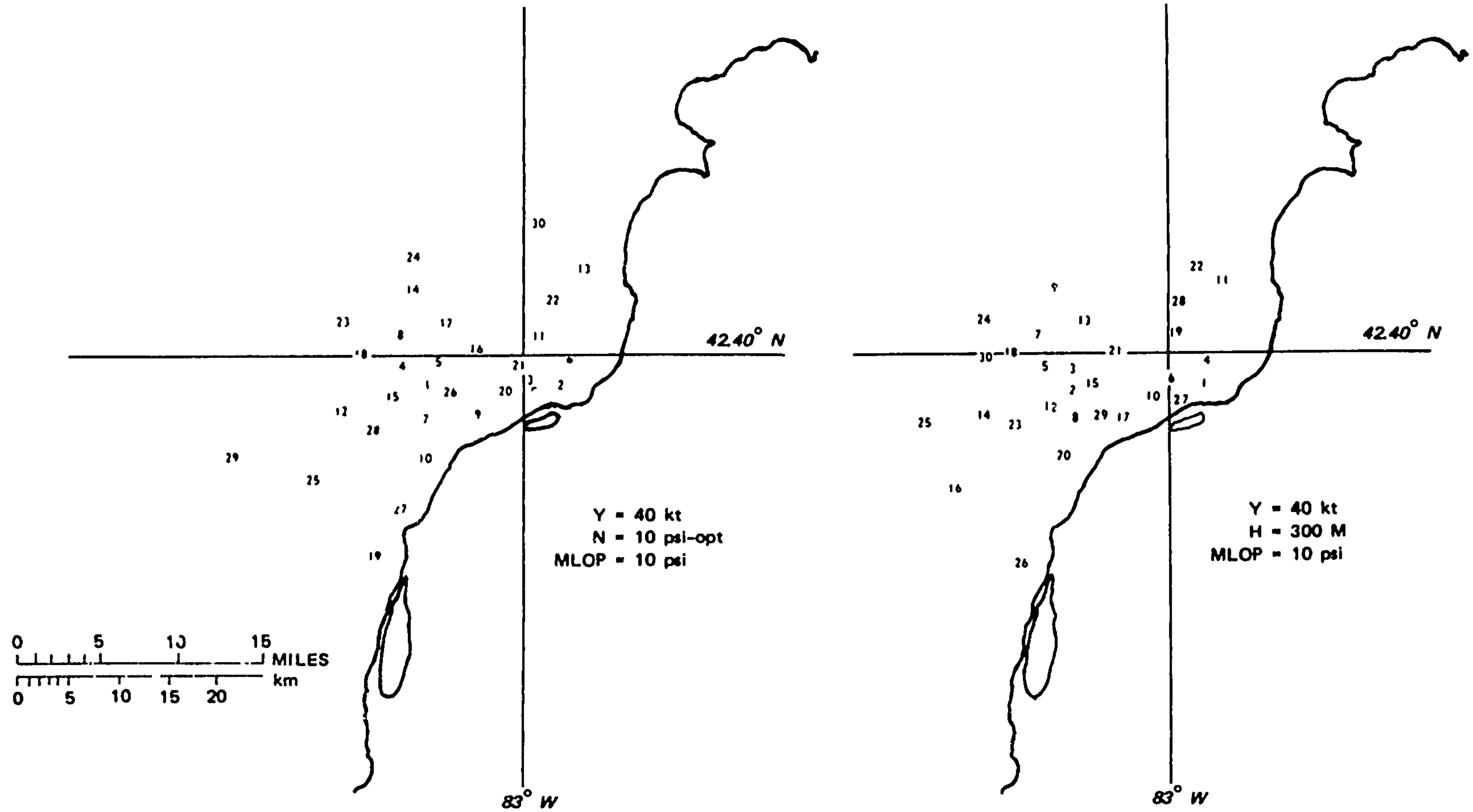
*5-kt weapons were included for completeness--it is unlikely they would ever be used for nuclear attacks on a city, but they do have tactical significance, and they may also represent the kind of threat that might be posed by saboteurs.

†It was found that in some situations the weapon laydown was not fully optimized, but that the $(n + 1)^{th}$ weapon sometimes resulted in a higher number of blast fatalities, by perhaps 15%, than the n^{th} weapon. This was recognized in the development of the program, and an option allows for correcting this situation by removing all previous weapons with lower fatalities and inserting the new weapon. However, exercising this option results in considerably longer running time for the program, and produces only marginally better optimization.[16]



(a) WEAPONS EXPLODED AT THE 10-psi-OPTIMIZED H.O.B.

(b) WEAPONS EXPLODED AT 300-m H.O.B.

FIGURE 13 LAYDOWN PATTERN FOR FIRST THIRTY 40-kt WEAPONS

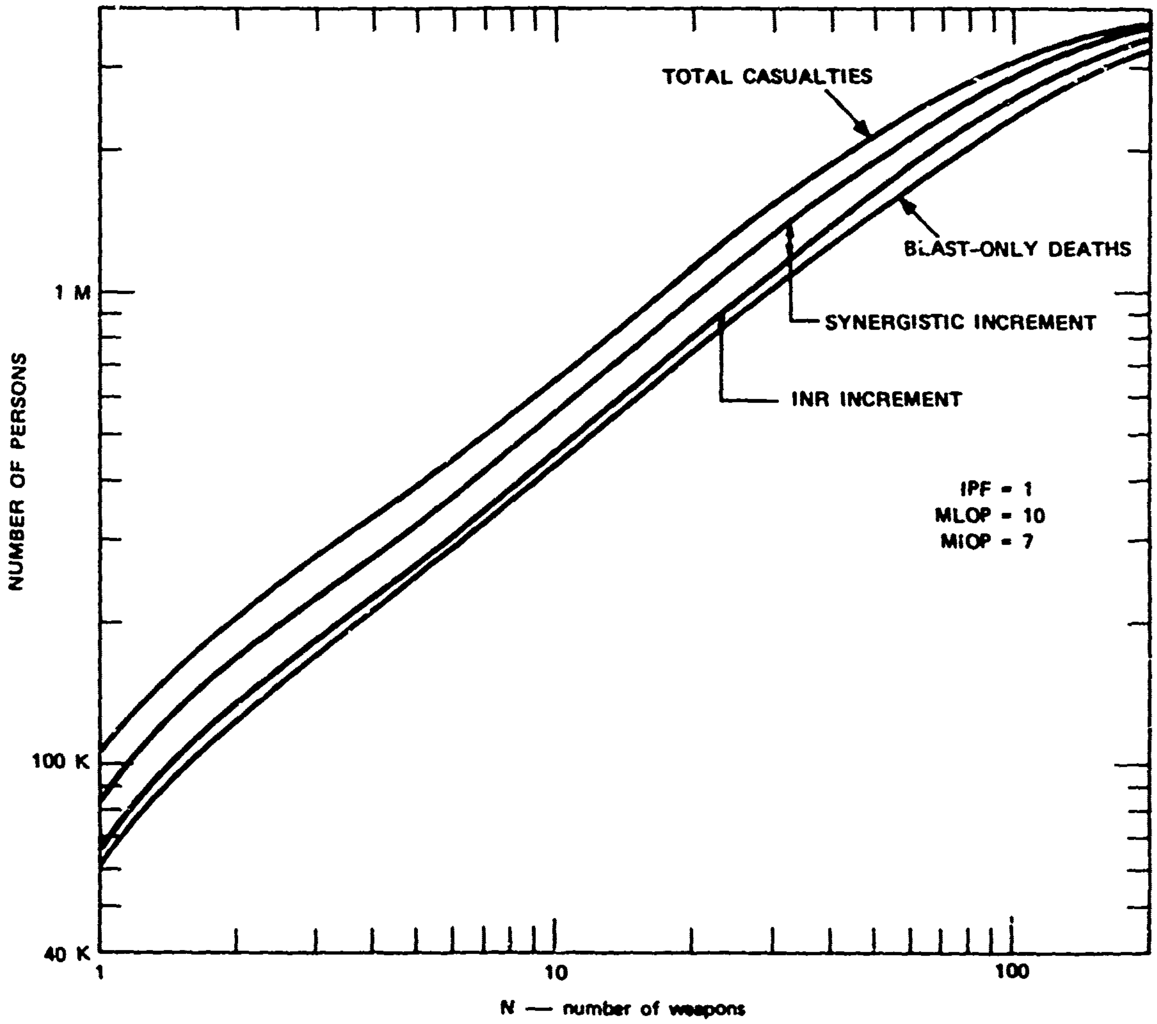


FIGURE 14 CASUALTIES vs. NUMBER OF 40-kt WEAPONS AT 10-psi-OPTIMIZED H.O.B.

Figure 15 presents the same results for an attack based on 40-kt weapons exploded at 300-m h.o.b. Because 300 m is less than the optimum altitude for maximizing 10 psi or greater overpressure the blast-only fatalities are less than in the previous figure and the INR increment is larger.

In presenting results, the attacks that are based on heights of burst optimized for 10 psi overpressure are emphasized as the worst case from the point of view of blast fatalities. Additionally, weapons exploding below 300 m will cause significant residual radiation due to fallout production for yields greater than 70 kt.

Attacks with 40-kt weapons turned out to be the worst case, and their results are emphasized here.

Except for the first two weapons, it is apparent that each additional weapon causes fewer deaths than the previous ones, with the curve rising almost linearly (on log-log paper) to 55 to 65 weapons, and then rising progressively more slowly as it approaches the asymptote of 3.9 million deaths.

Figure 16 shows the number of persons exposed to a free-field dose level of at least 50 rad, 200 rad, and 450 rad for the 40-kt, 10-psi-optimized case used for Figure 14. The radiation exposure of the population is assumed independent of the MLOP of the shelters considered, and for a given yield and h.o.b. is dependent only on the shelter IPF, taken to be unity here.

Figure 17 shows the percentage increase in deaths due to INR over blast alone for the same situation as that shown in Figure 14. Also shown is the fraction of the population subjected to dual radiation-blast injuries (synergistic increment) for INR between 50 and 450 rad. Here the increase in deaths due only to INR is seen to vary between 5 and 10%. It sould be noted that this would probably be higher if the laydown were not overpressure-optimized. It is interesting to note a gradual rise in this increment as the number of weapons increases, showing the additive nature of radiation injury. The upper curve in the figure shows a decrease in the percentage of persons subjected to dual injuries as the

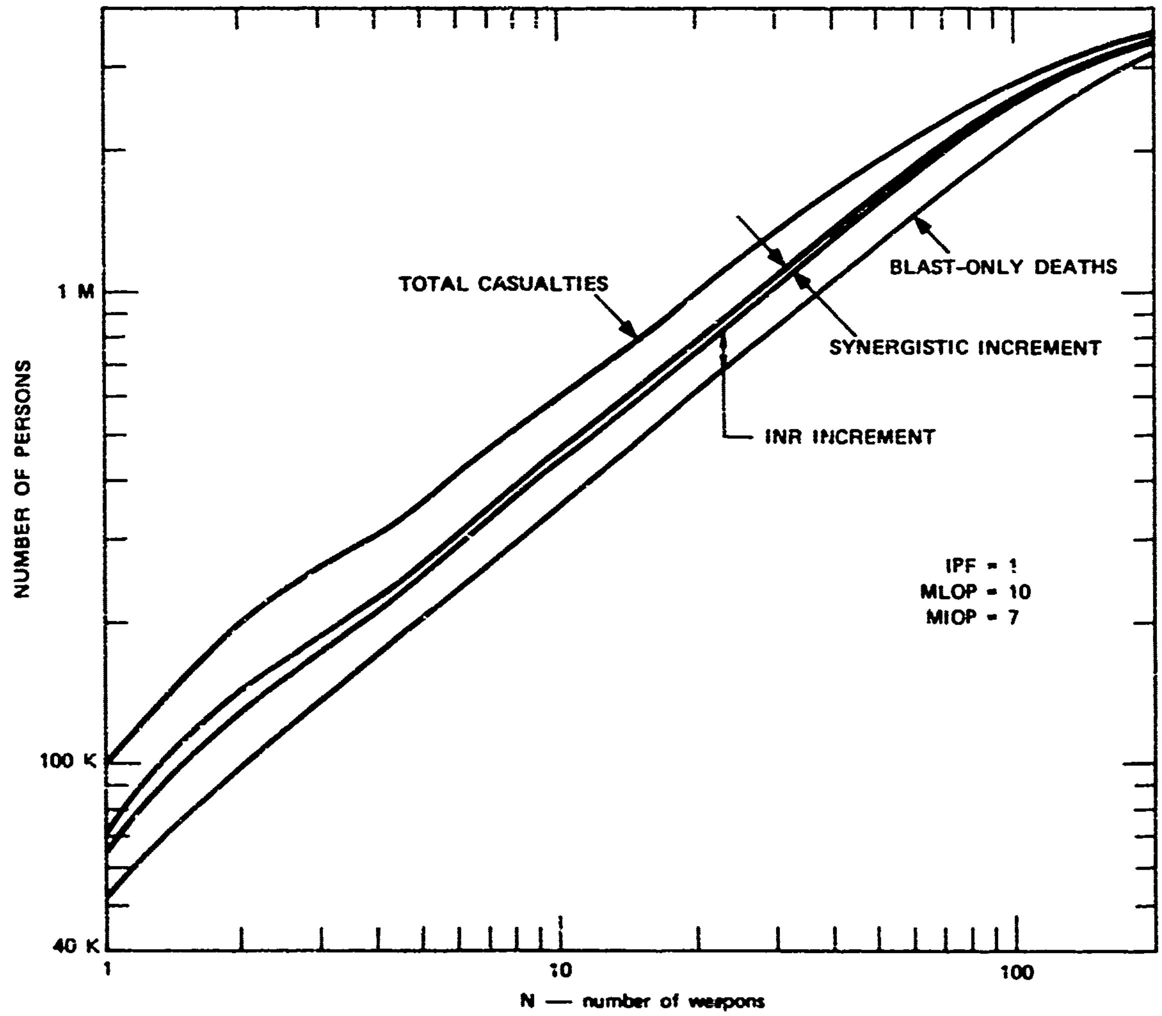


FIGURE 15 CASUALTIES vs. NUMBER OF 40-kt WEAPONS AT 300-m H.O.B.

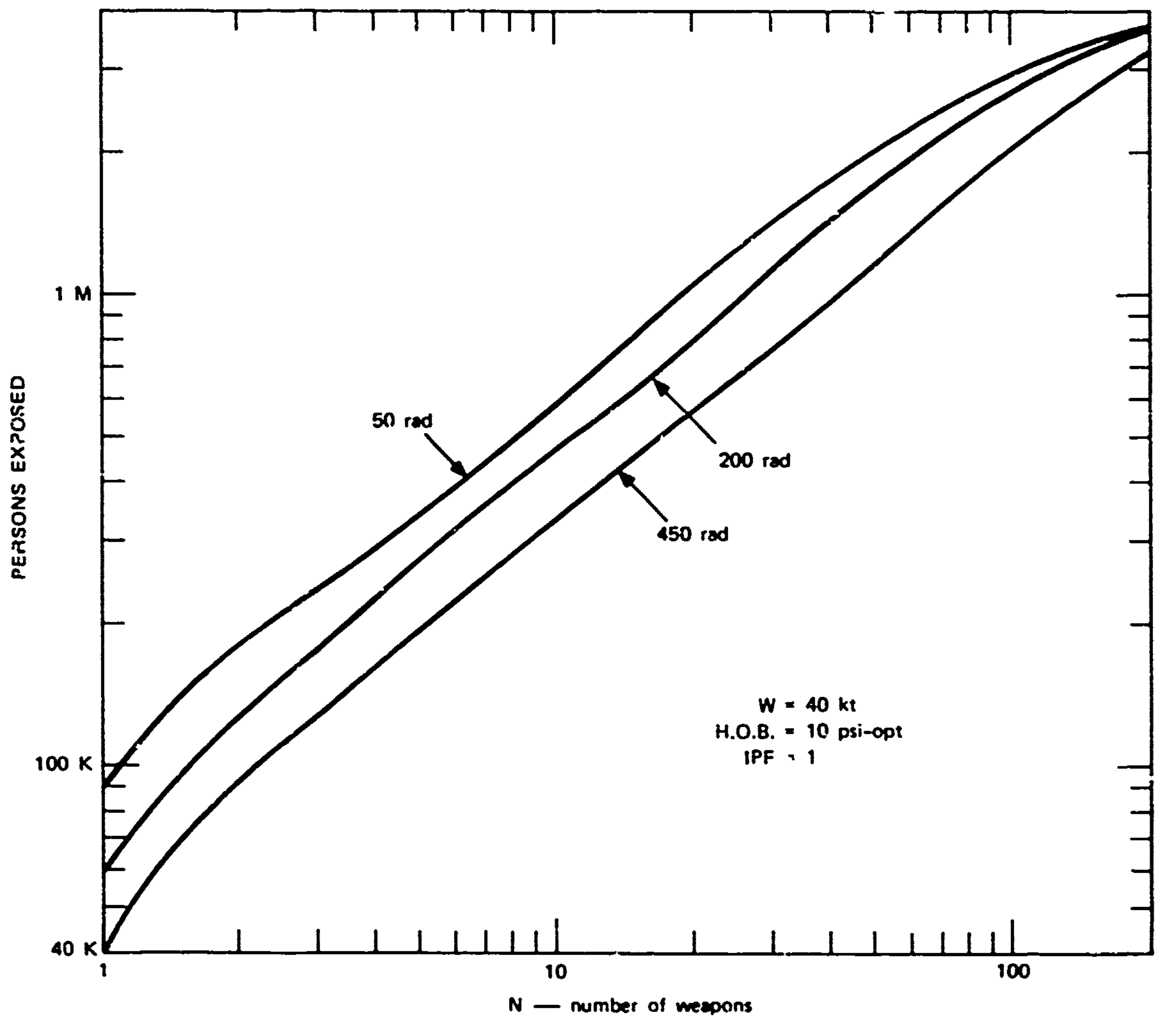


FIGURE 16 NUMBER OF PERSONS EXPOSED TO GREATER THAN INDICATED RADIATION LEVEL vs. NUMBER OF WEAPONS

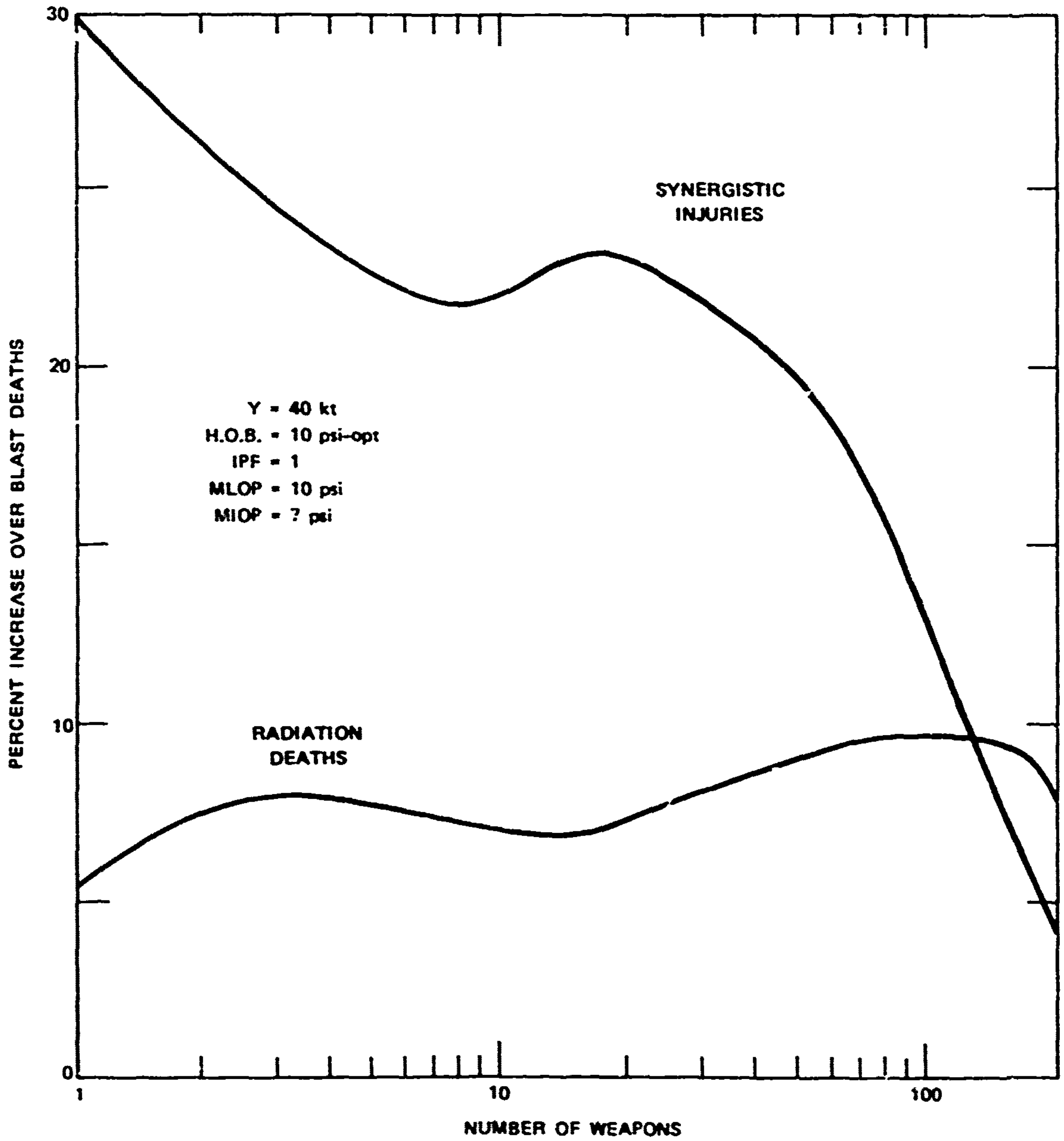


FIGURE 17 PERCENT INCREASE DUE TO RADIATION OVER BLAST DEATHS vs. NUMBER OF WEAPONS

number of weapons increases. The irregularities at small numbers of weapons are due to population inhomogeneity as well as to the computer-introduced artificiality resulting from the population data base placing up to 15,000 persons at one location.

If the initial radiation protection factor, IPF, is increased, the number of radiation-induced additional deaths decreases. This effect is shown in Figure 18 for IPFs between 1 and 100. The curves labeled MLOP = 10 psi used the same data as Figure 14. That labeled MLOP 15 was for a scenario where the population was sheltered with an MLOP of 15 psi and an MIOP of 14 psi. The two curves labeled ΔRdn show the expected decrease as more radiation protection is applied. Although the synergistic increment decreases for increasing IPF for MLOP = 10, it first rises for MLOP = 15 and then decreases. This results from the shifting of persons receiving a fatal radiation dose (>450 rad) into the radiation sickness range (50 to 450 rad), with a lesser number of persons being shifted to lower than 50 rad. An important result obvious from Figure 18 is that the synergistic increment for the MLOP = 10 psi, MIOP = 7 psi case is three to greater than 8 times larger than the radiation increment for IPFs up to 8, and is predominant for IPFs greater than 8. If one presumed that the synergism greatly increases the likelihood of death of a victim, the synergistic case becomes very important. For the MLOP = 15 psi, MIOP = 14 psi case, the synergistic increment predominates for IPFs greater than 7.5, and is greater than 10% of the blast-only deaths up to IPF = 33.

The percentage increase in deaths due to radiation was examined. Figure 19 shows the IPF required to limit this radiation increment to various percentages from 5 to 100% as a function of the MLOP to which the population is protected. This figure is also developed from the 40-kt, 10-weapon attack at 10-psi-optimized altitude.

To examine the dependence of the radiation increment on weapon yield and blast protection, additional attack scenarios were computed. These are summarized in Figure 20. Here we show the IPFs needed to limit the radiation increment to 10 and 25% for 5, 40, 200, and 1000 kt.

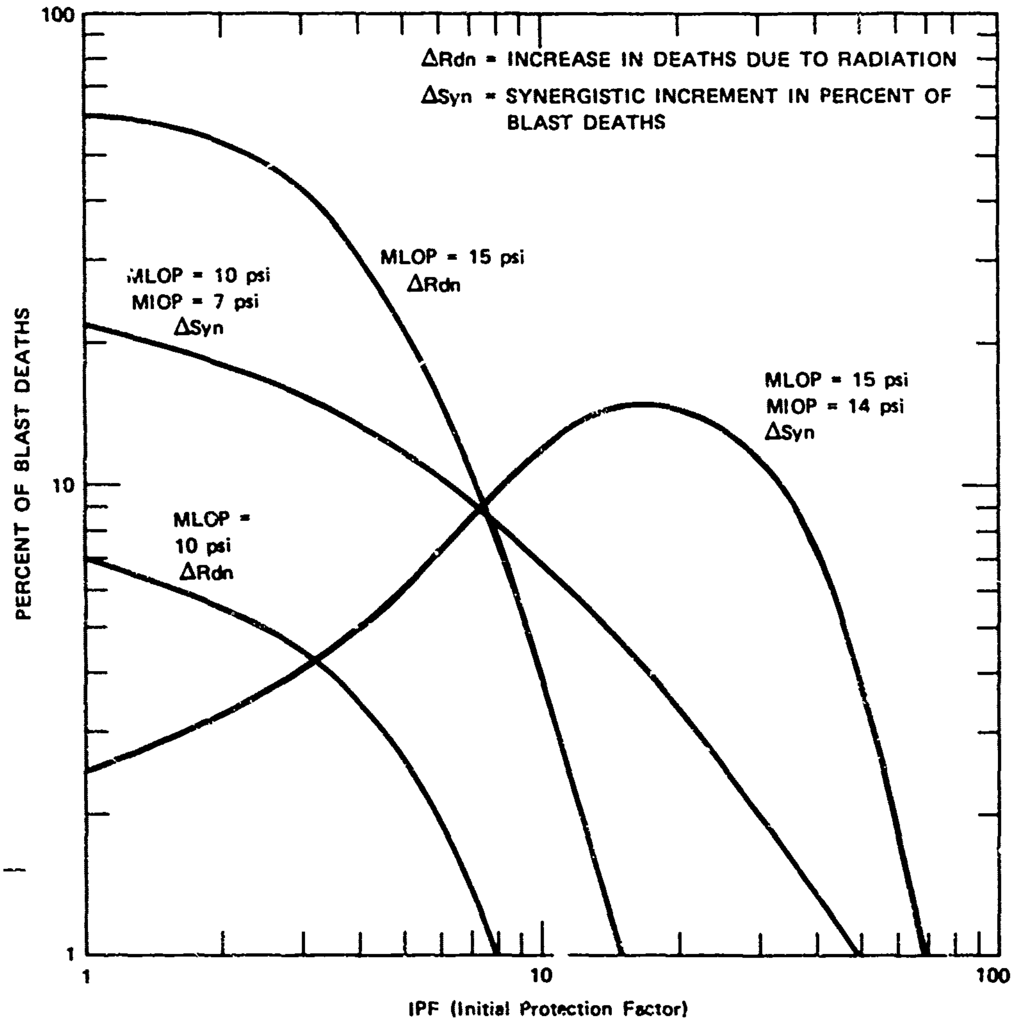


FIGURE 18 EFFECTS ON RADIATION-DEATH INCREMENT AND SYNERGISTIC INCREMENT OF INCREASING IPF--40 kt, 10 WEAPONS

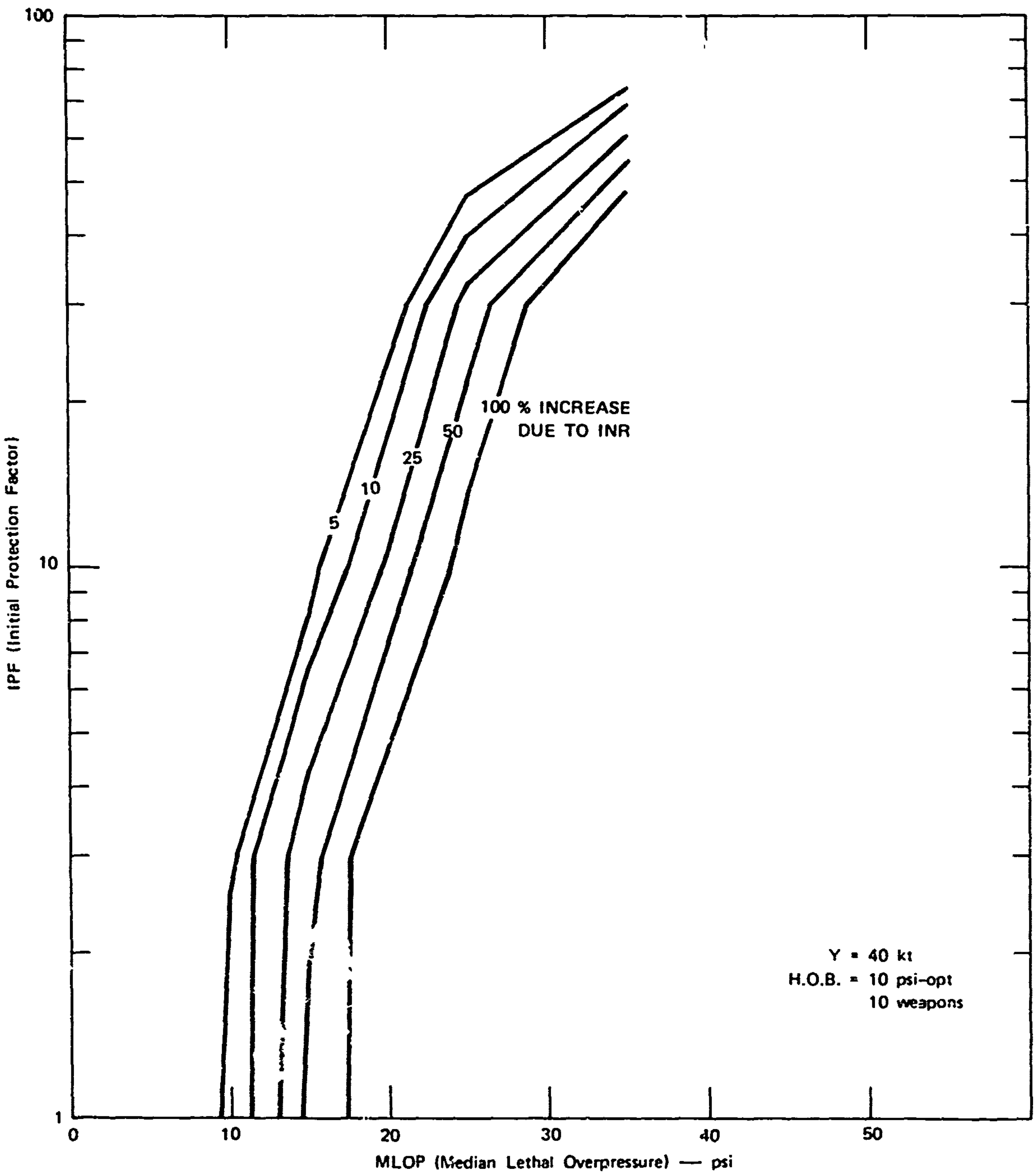


FIGURE 19 IPF REQUIRED TO LIMIT RADIATION INCREMENT TO GIVEN PERCENTAGE OF BLAST-ONLY DEATHS vs. MLOP

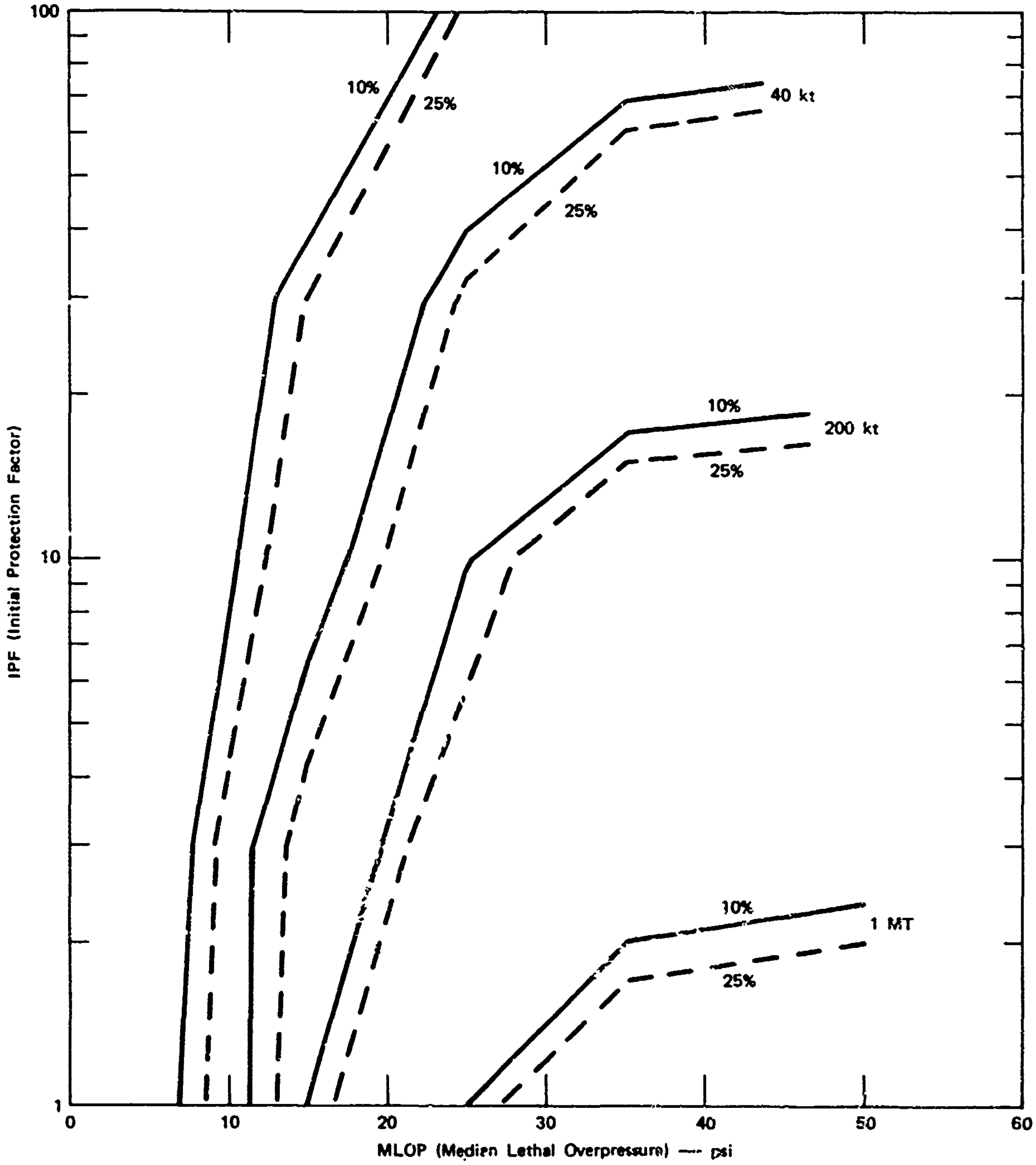


FIGURE 20 IPFs NEEDED TO LIMIT ADDITIONAL DEATHS TO 10 AND 25 PERCENT FOR 5-kt, 40-kt, 200-kt, AND 1-Mt ATTACKS vs. MLOP (10-psi-optimized altitude)

It is apparent from Figure 20 that protection against initial nuclear radiation is significantly more important for lower-yield weapons than for larger ones. Obviously, the radiation protection requirement for a shelter depends on the presumed threat, as well as the shelter blast protection rating. If the attack is of 5-kt weapons, a very large IPF (IPF = 70 for 10% increase) is needed, even for 20 psi MLOP. For 40-kt weapons, the IPF needed to limit fatalities due to INR to 10% that of 20-psi MLOP decreases to about 13, and for 200 kt to 2. For 1-Mt weapons, no radiation protection is needed. This is shown in Figure 21 for MLOPs of 10 and 25 psi.

If the blast protection is increased to an MLOP of 35 psi, the need for INR protection becomes more notable. For 5-kt weapons, the required IPF is very large, perhaps several hundred, to limit the additional INR deaths to 10% of those due to blast. The needed IPF is 50 for 40 kt weapons, 12 for 200 kt, and slightly greater than 1 for 1 Mt.

The effect of varying the yield of the weapons while holding the h.o.b. constant was examined. The h.o.b. was fixed at 300 m altitude. This altitude was chosen for comparative purposes only. Weapons with yields above 70 kt would produce fallout that could exceed the effects of INR at this h.o.b. The results are shown in Figure 22, to be compared to those of Figure 20. This study was done for weapon yields of 40, 200, and 1000 kt.

Apparent in the comparison is the effect of decreasing the height of burst below the 10-psi-optimized height. For all three cases shown, the required IPF for any MLOP protection is higher than for the 10-psi-optimized attacks. The latter have higher burst altitudes and longer slant ranges to any point on the ground.

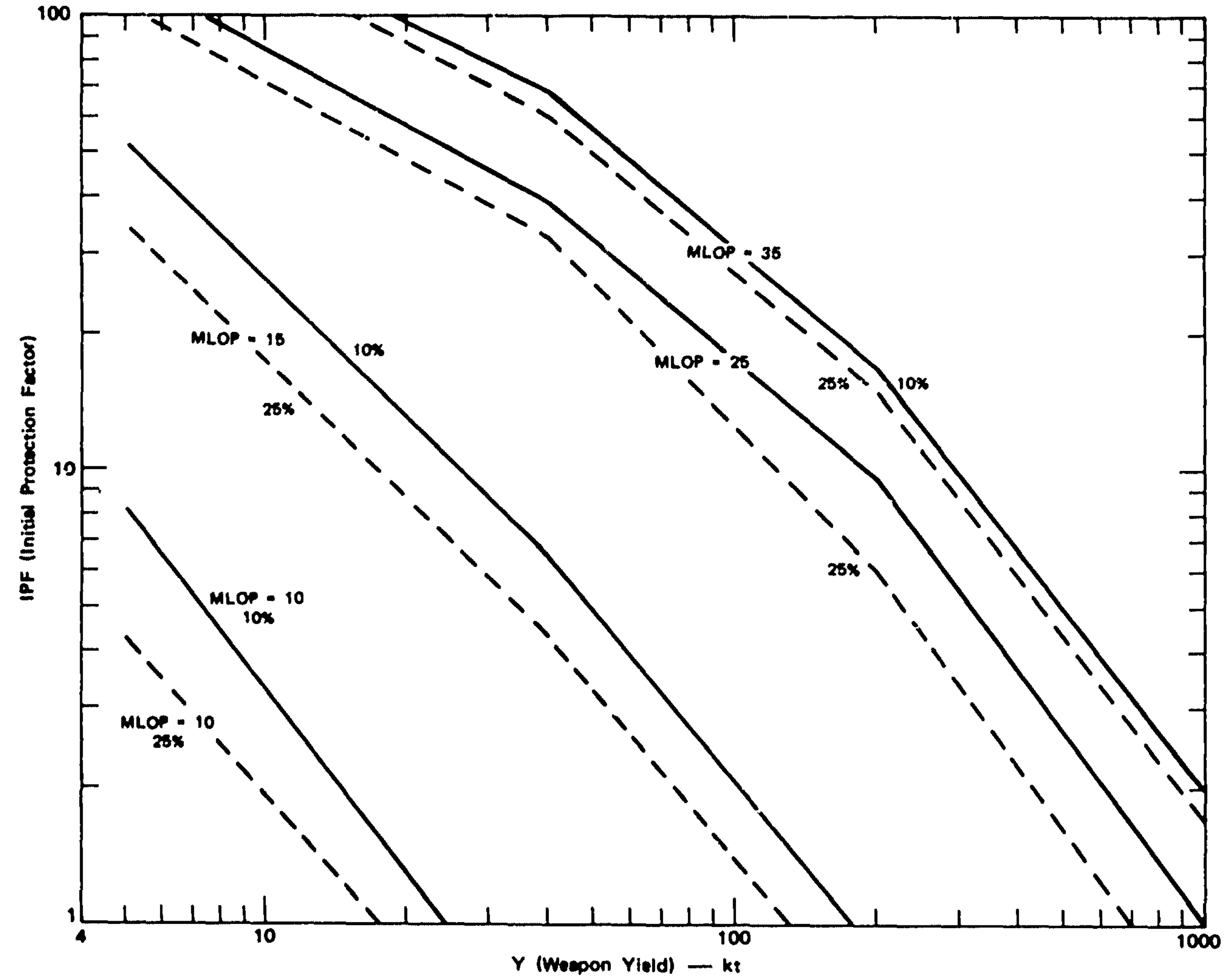


FIGURE 21 RADIATION PROTECTION REQUIRED TO LIMIT ADDITIONAL FATALITIES TO 10 AND 25 PERCENT AS A FUNCTION OF WEAPON YIELD (10-psi-optimized H.O.B.)

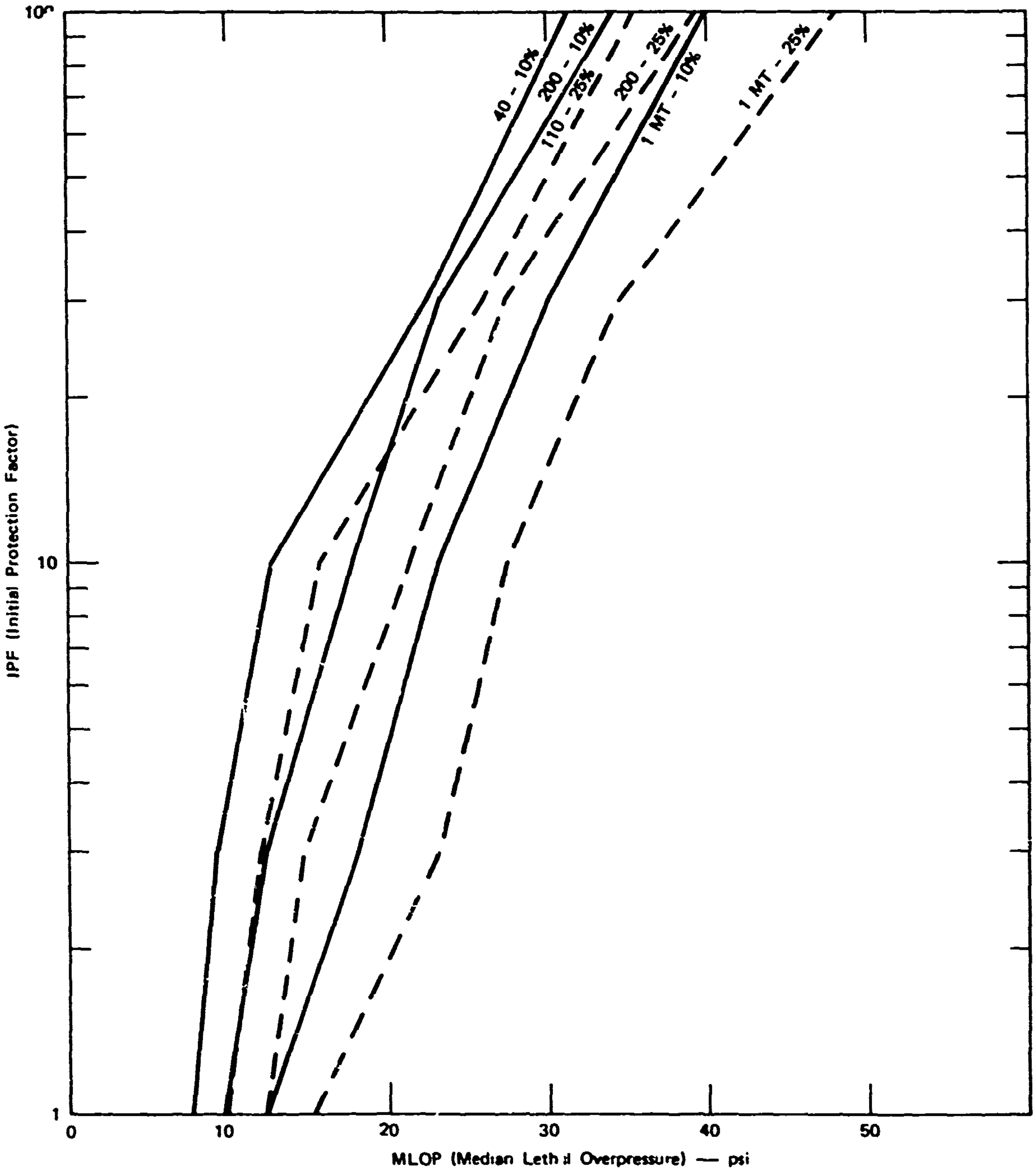


FIGURE 22 IPFs NEEDED TO LIMIT ADDITIONAL DEATHS TO 10 AND 25 PERCENT FOR 40-kt, 200-kt, AND 1-Mt ATTACKS vs. MLOP (300-m H.O.B.)

V CONCLUSIONS

The amount of initial nuclear radiation protection needed to protect a sheltered civilian population against excessive additional deaths due to initial radiation (over those resulting from blast alone) has been determined as a function of the yield of the nuclear weapons involved in the attack, the amount of blast protection afforded by the shelter, and the height-of-burst of the weapons.

The percentage increase in deaths due to radiation and/or blast (for a fixed IPF) over that due to blast only was shown to be of greater significance for lower-yield weapons as compared to higher-yield ones. Conversely, to maintain a fixed percentage increase (over blast-only deaths) in the number of fatalities due to consideration of initial radiation, larger IPFs were needed as the weapon yield was decreased. If deaths resulting from synergistic effects--i.e., from dual radiation and blast injuries--are not considered, it was shown that a 10% or greater increase in deaths (over blast alone) would result from nuclear radiation for a radiation-unprotected population attacked by 40-kt weapons and in a shelter with at least 11-psi median lethal overpressure protection factor (MLOP). For 200-kt weapons, the increase in deaths would equal or exceed 10% for shelters whose MLOP is 15 psi or greater, or for MLOPs greater than 25 psi for 1-Mt weapons. (The heights of burst were those that would maximize the area exposed to 10 psi or greater.) If the IPFs are increased to 10, the thresholds for 10% increased deaths due to radiation are 18 and 26 psi for 40- and 200-kt weapons, respectively. No additional radiation-induced deaths occur for 1-Mt weapons for MLOPs of 55 psi or less and IPFs of 3 or greater.

The fractional increase of persons with synergistic radiation-blast injuries depends on both the median injury overpressure (MIOP) rating of a shelter and the MLOP. It also depends on the presumed threshold for radiation injury and the shelter IPF. A notably higher IPF would be

required to keep the incremental increase in deaths at a fixed value when both radiation deaths and deaths from dual radiation-blast injuries are considered. The synergistic case takes on added importance if one considers the demands made by this group on the post-attack medical capability. This group, as well as the radiation illness group (without blast injury), becomes even more important if fallout causes additional radiation exposure after an attack.

VI RECOMMENDATIONS

It was seen that the increase in deaths due to radiation can be limited to reasonable values by the use of radiation protection in addition to blast protection. This is of importance for attacks by submegaton weapons, becoming more important as the weapon yield decreases. It is recommended that the curves labeled 10% on Figure 20 for 40 and 200 kt be given serious consideration in the design of shelters to protect populations against the prompt effects of nuclear weapons.

A great deal of data remains in the ANDANTE computer runs that was not analyzed within the constraints of this program. Additional study would be desirable to extract further useful information from the computer-produced data.

As an example of importance, an in-depth investigation of the magnitude of synergistic blast-radiation-induced deaths would be valuable. This group of casualties would require major attention from an already overcommitted medical capability following an attack, and therefore, the magnitude of the problem is important for future post-attack recovery planning. Additional study is recommended to determine the number of dual injuries for different radiation levels and MIOPs to estimate the magnitude of the dual-injury problem. For example, if one presumes that a dose between 200 and 450 rad along with blast injuries would result in serious medical problems and high likelihood of subsequent death, then studies should be done to determine the IPFs for different blast protection against death and injury to limit both death and serious synergistic injuries, rather than death alone.

This study was based on only a portion of the information produced in the ANDANTE computer runs. It is recommended that further analysis be done and the results displayed, for the full variety of weapon yields, MLOPs, and MIOPs used for both heights-of-burst, and for the range of IPFs examined.

Appendix A

THE ANDANTE COMPUTER CODE

Appendix A

THE ANDANTE COMPUTER CODE

The current ANDANTE computer code has evolved from a series of nuclear weapon attack codes, and has itself been improved several times. ANDANTE is maintained by the Defense Civil Preparedness Agency at the DCPA Computer Center in Olney, Maryland. It was prepared by Dr. Leo Schmidt, of the Institute for Defense Analysis, and it simulates a multi-weapon nuclear attack on a city, with a large variety of initial conditions being allowed.[15] It examines the effects of blast, initial nuclear radiation, and thermal exposure on the exposed population.

The target city is defined in terms of a population data base derived from census data. Population groups are presumed to be grouped at the census points. The census points need not be located on intersection points of a rectangular grid, but can be grouped in any convenient manner. The population data base for the Greater Detroit area that was used in this study was extracted from the U.S. Census Bureau MEDLIST file of 1970 data extrapolated to 1975.[16] It includes all people living within the urbanized areas of Detroit, and includes, in general, all areas contiguous to the central city with population densities greater than 1000 people per square mile. In this study the population data base was condensed to 974 census points, each representing up to 15,000 persons,[17] with a total population of about 3,900,000.

Variables in the ANDANTE program that apply to the weapons include yield, number of weapons, and height of burst. In this study, the yields examined were 5 kt, 40 kt, 200 kt, and 1 Mt. Heights of burst were 300 m and the altitude that maximized the area exposed to more than 10 psi. The computer program has the capability of "optimizing" the laydown pattern of nuclear weapons of the specified yield and height of burst so as to maximize the number of fatalities for a chosen median lethal overpressure (MLOP) protection level. In the optimization routine, the first

weapon is targeted at that point that will result in the maximum number of fatalities. This target point is then fixed, the fatalities from this weapon are subtracted from the data base, and the second weapon is then targeted at the point that will again maximize the number of fatalities in the residual population. This process is repeated until all the weapons specified have been targeted or until a specified percentage of fatalities is reached. No changes are made in the target location of a given weapon, once determined. For the study reported here, all laydown patterns were chosen to maximize fatalities for an MLOP of 10 psi. The maximum number of weapons for a given yield was limited to 199 weapons or to the number that would cause 95% fatalities if all persons were protected to an MLOP of 10 psi.

ANDANTE allows for the specification of a circular error probability (CEP) for the weapons--that is, for a statistical deviation of the actual explosion point of the weapons. This was held at zero for this study. Also allowed is the variation of the delivery probability of each weapon--using a Monte Carlo technique. All weapons were assumed to be delivered for this study.

The weapon type, and hence its nuclear spectrum, can be specified in terms of the ratio of fission yield to total yield of the weapon. This provides a reasonable approximation without requiring detailed knowledge of specific differences in weapon desig... Most calculations reported here are based on a 100% fission weapon as the worse case for INR. Some calculations were done for a 50% fission thermonuclear weapon to test the differences in casualties, and some calculations were also made for a hypothetical enhanced-radiation low-yield weapon by modifying the program to increase the neutron output by a factor of five.

The peak pressure at each census point, as a result of each weapon, is determined through use of a curve fit to the data shown on Figures 2 and 3. Only the peak overpressure from the closest weapon is considered in the blast lethality/injury computations. For the 10-psi-optimized attack, the overpressure (in psi), p, is given by

$$p = \frac{86.82\ W^{1/3}}{R^2} + \frac{4\ W^{1/3}}{R} + 0.232 \qquad \text{for } R > 3.11\ W^{1/3}$$

$$= 9.8 \qquad \text{for } R = 3.11\ W^{1/3}$$

$$= \frac{105.5\ W^{2/3}}{R^2} - \frac{49.93\ W^{1/3}}{R} + 15.23 \qquad \text{for } 0 < R < 3.11\ W^{1/3}$$

where W is the weapon yield in megatons, and R is the slant range in statute miles.[16]

For a burst of 300 m height, the following expressions are used for W less than 1 Mt:

$$p = 10^a\ R^b \qquad \text{if } R < \left(\frac{50}{10^a}\right)^{1/b}$$

$$= 10^A\ R^B \qquad \text{if } R > \left(\frac{50}{10^a}\right)^{1/b} .$$

The values of the constants for a few selected yields are given in Table A-1.

Table A-1

VALUES OF CONSTANTS FOR SELECTED YIELDS

Yield (kt)	a	A	b	B
40	-0.4546	0.7838	-4.577	-1.945
100	0.3678	1.0049	-3.596	-1.875
200	0.7795	1.1767	-3.160	-1.795
300	0.9342	1.2520	-3.055	-1.825
500	1.2434	1.4023	-2.807	-1.828

For yields greater than 1 Mt at a height-of-burst of 300 m, the following expression was used by the computer program:

$$p = \frac{35.5\ W^{2/3}}{R^2} + \frac{0.6013\ W^{1/3}}{R^2} + 0.3763\ .$$

After determination of the overpressures to which each group of persons located at the census points is subjected, the blast vulnerability discussed earlier is applied to determine the number of persons at each point who are killed or injured. All the census points are then summed.

The initial radiation resulting from an attack is included in the computer program as a subroutine that computes the dose from fission product gamma radiation, secondary gamma radiation, and neutrons. The algorithms used to determine the dose at the radial distance R_o due to the latter two sources were developed by C. M. Eisenhauer:

$$D = a \exp b\ [\exp\ (cR_o^2 + dR_o)]\ , \qquad a,\ b,\ c,\ d \text{ constant,}$$

and are based on a paper by French and Mooney.[18,19] The fission product gamma dose emitted from the rising nuclear debris is significantly more complex and is estimated in Ref. 20.

Radiation dose at each census point is summed for all weapons in the attack.

The computer program allows for the assignment of an initial radiation protection factor, IPF, to the census points. As described earlier, the IPF is numerically equal to the protection of initial radiation afforded by a shelter--i.e., the ratio of free-field radiation dose to that received within a shelter. The IPF was varied to determine what radiation protection would be needed to limit the increase in casualties to different percentages over blast-only casualties. For a given computer run, the entire population is assumed to be housed in the same type of shelter.

The ANDANTE program provides a detailed output format. If more than one weapon is specified, it will list the results from each weapon in order of decreasing effect. Therefore, it is possible to examine an attack of any number of weapons less than the maximum number. The results of the calculations are reported in a large variety of ways. Reported are: numbers of fatalities and injuries due only to radiation or only to blast, number of persons who would have been killed by either blast or radiation alone, and synergistic fatalities (requires a synergism factor or will print out the total number of persons suffering dual injuries). Additionally, uninjured are reported. The most concise output listing is in the form of a matrix as shown in Table A-2. One matrix is reported for each number of weapons exploded up to the maximum specified.

Table A-2

CASUALTIES RESULTING FROM TEN OPTIMALLY PLACED 40-kt WEAPONS AT 10-psi-OPTIMIZED ALTITUDE--MLOP = 10 psi; MIOP = 7 psi; IPF = 1 (3 RADIATION GROUPS)

Blast / Radiation	Fatalities	Injuries	Uninjured
F (>450 rad)	302007	26610	3764
I (50-450 rad)	123273	94647	41729
U (<50 rad)	9285	43865	3287150

Repeating the computation but replacing the median sickness dose (radiation) by 200 rad, and combining the results, provides a 3 x 4 matrix that shows both the moderately ill (MI) and seriously ill (SI) due to radiation. This is shown in Table A-3; the same case as Table A-2.

Table A-4 is a repeat of Table A-3, with the different categories of casualties indicated.

Table A-3

CASUALTIES RESULTING FROM TEN OPTIMALLY PLACED 40-kt WEAPONS AT 10-psi-OPTIMIZED ALTITUDE--MLOP = 10 psi; MIOP = 7 psi; IPF = 1 (4 RADIATION GROUPS)

Radiation \ Blast	Fatalities	Injuries	Uninjured
Fatal (>450 rad)	302007	26610	3764
Seriously ill (200-450 rad)	82126	46478	13671
Mildly ill (50-200 rad)	41147	48169	28058
Uninjured (<50 rad)	9285	43865	3287150

Table A-4

TABLE A-3, WITH DIFFERENT CATEGORIES OF CASUALTIES INDICATED

Radiation \ Blast	Fatalities	Injuries	Uninjured
Fatal (>450 rad)	302007	26610	3764
Seriously ill (200-450 rad)	82126	46478	13671
Mildly ill (50-200 rad)	41147	48169	28058
Uninjured (<50 rad)	9285	43865	3287150

The sum of all four numbers within box 'a' is that number of persons who have died as a result of blast, irrespective of the presence of radiation. Box 'b' includes the incremental increase in fatalities due to the presence of radiation. Box 'c' includes the additional number of persons who are injured by radiation, but not by blast. Box 'd'

represents those persons who are doubly injured--that is, injured by blast in the absence of radiation and by radiation in the absence of blast. This group of persons is discussed in Section II-G of the main text. As the ability to recover from injuries due to blast will be diminished by the effects of radiation, some of these persons suffering "synergistic injuries" will die.

Additional matrices of casualties for different input parameters are given in Appendix B.

Appendix B

SELECTED CASUALTY MATRICES

Appendix B

SELECTED CASUALTY MATRICES

To allow the reader to directly compare the effects of changing the input parameters to the ANDANTE code, casualty matrices, as described in Appendix A, are presented for the following parameters:

Yield: 40 kt or 1000 kt

Height: 10-psi-optimized or 300 m

MLOP: 4, 10, or 15 psi

IPF: 1 or 10.

Each casualty matrix is based on an attack of ten weapons.

Sample 1

Y = 40 kt
h.o.b. = 10 psi-opt
MLOP = 4 psi
MIOP = 2 psi
IPF = 1

Radiation \ Blast	Fatalities	Injuries	Uninjured
Fatal (>450 rad)	332348	33	0
Seriously Ill (200-450 rad)	141430	843	1
Mildly Ill (50-200 rad)	115462	1911	1
Uninjured (<50 rad)	245727	300896	2793676

Sample 2

Y = 40 kt
h.o.b. = 10 psi-opt
MLOP = 10 psi
MIOP = 7 psi
IPF = 1

Radiation \ Blast	Fatalities	Injuries	Uninjured
Fatal (>450 rad)	302007	26610	3764
Seriously Ill (200-450 rad)	82126	46478	13671
Mildly Ill (50-200 rad)	41147	48169	28058
Uninjured (<50 rad)	9285	43865	3287150

Sample 3

Y = 40 kt
h.o.b. = 10 psi-opt
MLOP = 15 psi
MIOP = 14 psi
IPF = 1

Radiation \ Blast	Fatalities	Injuries	Uninjured
Fatal (>450 rad)	205369	29595	97417
Seriously Ill (200-450 rad)	4755	4700	132819
Mildly Ill (50-200 rad)	1074	525	115777
Uninjured (<50 rad)	0	0	3380544

Sample 4

Y 40 kt

h.o.b. = 10 psi-opt

MLOP = 4 psi

MIOP = 2 psi

IPF = 10

Radiation \ Blast	Fatalities	Injuries	Uninjured
Fatal (>450 rad)	117739	2	0
Seriously Ill (200-450 rad)	127249	12	0
Mildly Ill (50-200 rad)	82346	19	0
Uninjured (<50 rad)	507633	303650	2793678

Sample 5

Y = 40 kt

h.o.b. = 10 psi-opt

MLOP = 10 psi

MIOP = 7psi

IPF = 10

Radiation \ Blast	Fatalities	Injuries	Uninjured
Fatal (>450 rad)	115796	1816	129
Seriously Ill (200-450 rad)	116748	9389	1124
Mildly Ill (50-200 rad)	65863	14127	2375
Uninjured (<50 rad)	136157	139791	3329015

Sample 6

Y = 40 kt

h.o.b. = 10 psi-opt

MLOP = 15 psi

MIOP = 14 psi

IPF = 10

Radiation \ Blast	Fatalities	Injuries	Uninjured
Fatal (>450 rad)	110139	3425	4176
Seriously Ill (200-450 rad)	75740	16346	35175
Mildly Ill (50-200 rad)	19195	9563	53606
Uninjured (<50 rad)	6123	5485	3593355

Sample 7

Y = 40 kt
h.o.b. = 300 m
MLOP = 4 psi
MIOP = 2 psi
IPF = 1

Radiation \ Blast	Fatalities	Injuries	Uninjured
Fatal (>450 rad)	433504	2231	14
Seriously Ill (200-450 rad)	46233	4526	196
Mildly Ill (50-200 rad)	80429	27883	1360
Uninjured (<50 rad)	42508	232618	3060826

Sample 8

Y = 40 kt
h.o.b. = 300 m
MLOP = 10 psi
MIOP = 7 psi
IPF = 1

Radiation \ Blast	Fatalities	Injuries	Uninjured
Fatal (>450 rad)	345941	57113	32675
Seriously Ill (200-450 rad)	2735	12660	35560
Mildly Ill (50-200 rad)	1748	12973	94952
Uninjured (<50 rad)	109	1767	3334077

Sample 9

Y = 40 kt
h.o.b. = 300 m
MLOP = 15 psi
MIOP = 14 psi
IPF = 1

Radiation \ Blast	Fatalities	Injuries	Uninjured
Fatal (>450 rad)	241273	23363	171113
Seriously Ill (200-450 rad)	0	0	50955
Mildly Ill (50-200 rad)	0	0	109673
Uninjured (<50 rad)	0	0	3335953

Sample 10

Y = 40 kt
h.o.b. = 300 m
MLOP = 4 psi
MIOP = 2 psi
IPF = 7

Radiation \ Blast	Fatalities	Injuries	Uninjured
Fatal (>450 rad)	290062	24	0
Seriously Ill (200-450 rad)	69496	428	0
Mildly Ill (50-200 rad)	63300	1486	2
Uninjured (<50 rad)	179817	265321	3062394

Sample 11

Y = 40 kt
h.o.b. = 300 m
MLOP = 10 psi
MIOP = 7 psi
IPF = 1

Radiation \ Blast	Fatalities	Injuries	Uninjured
Fatal (>450 rad)	277688	8859	3539
Seriously Il (200-450 rad)	48021	17977	3926
Mildly Ill (50-200 rad)	19093	26230	19465
Uninjured (<50 rad)	5732	31467	3470333

Sample 12

Y = 40 kt
h.o.b. = 300 m
MLOP = 15 psi
MIOP = 14 psi
IPF = 1

Radiation \ Blast	Fatalities	Injuries	Uninjured
Fatal (>450 rad)	233610	17884	38593
Seriously Ill (200-450 rad)	7436	5229	57259
Mildly Ill (50-200 rad)	227	251	64310
Uninjured (<50 rad)	0	0	3507532

Sample 13

Y = 1000 kt
h.o.b. = 10 psi-opt
MLOP = 4 psi
MIOP = 2 psi
IFP = 1

Radiation \ Blast	Fatalities	Injuries	Uninjured
Fatal (>450 rad)	149174	0	0
Seriously Ill (200-450 rad)	131973	0	0
Mildly Ill (50-200 rad)	256936	2	0
Uninjured (<50 rad)	2437549	382496	574194

Sample 14

Y = 1000 kt
h.o.b. = 10 psi-opt
MLOP = 10 psi
MIOP = 7 psi
IFP = 1

Radiation \ Blast	Fatalities	Injuries	Uninjured
Fatal (>450 rad)	149088	85	1
Seriously Ill (200-450 rad)	131530	407	36
Mildly Ill (50-200 rad)	251587	4972	379
Uninjured (<50 rad)	1345810	585395	1463036

Sample 15

Y = 1000 kt
h.o.b. = 10 psi-opt
MLOP = 15 psi
MIOP = 14 psi
IPF - 1

Radiation \ Blast	Fatalities	Injuries	Uninjured
Fatal (>450 rad)	149105	40	29
Seriously Ill (200-450 rad)	130579	867	527
Mildly Ill (50-200 rad)	238398	8025	10515
Uninjured (<50 rad)	400015	135184	2859043

Sample 16

Y = 1000 kt

h.o.b. = 10 psi-opt

MLOP = 4 psi

MIOP = 2 psi

IPF = 10

Radiation \ Blast	Fatalities	Injuries	Uninjured
Fatal (>450 rad)	0	0	0
Seriously Ill (200-450 rad)	0	0	0
Mildly Ill (50-200 rad)	130284	0	0
Uninjured (<50 rad)	2845347	382498	574194

Sample 17

Y = 1000 kt

h.o.b. = 10 psi-opt.

MLOP = 10 psi

MIOP = 7 psi

IPF = 10

Radiation \ Blast	Fatalities	Injuries	Uninjured
Fatal (>450 rad)	0	0	0
Seriously Ill (200-450 rad)	0	0	0
Mildly Ill (50-200 rad)	130231	52	1
Uninjured (<50 rad)	1747783	590806	1463451

Sample 18

Y = 1000 kt

h.o.b. = 10 psi-opt

MLOP = 15 psi

MIOP = 14 psi

IFP = 10

Radiation \ Blast	Fatalities	Injuries	Uninjured
Fatal (>450 rad)	0	0	0
Seriously Ill (200-450 rad)	0	0	0
Mildly Ill (50-200 rad)	130241	27	17
Uninjured (<50 rad)	787855	144089	2870097

Sample 19

Y = 1000 kt
h.o.b. = 300 m
MLOP = 4 psi
MIOP = 2 psi
IPF = 1

Radiation \ Blast	Fatalities	Injuries	Uninjured
Fatal (>450 rad)	1126963	333	1
Seriously Ill (200-450 rad)	141768	832	1
Mildly Ill (50-200 rad)	185367	1812	1
Uninjured (<50 rad)	678825	573166	1223257

Sample 20

Y = 1000 kt
h.o.b. = 300 m
MLOP = 10 psi
MIOP = 7 psi
IPF = 1

Radiation \ Blast	Fatalities	Injuries	Uninjured
Fatal (>450 rad)	1073340	41264	12693
Seriously Ill (200-450 rad)	100385	35303	6913
Mildly Ill (50-200 rad)	93736	71413	22031
Uninjured (<50 rad)	72974	183950	2218326

Sample 21

Y = 1000 kt
h.o.b. = 300 m
MLOP = 15 psi
MIOP = 14 psi
IPF = 1

Radiation \ Blast	Fatalities	Injuries	Uninjured
Fatal (>450 rad)	899609	58595	169093
Seriously Ill (200-450 rad)	13984	10780	117837
Mildly Ill (50-200 rad)	2868	3409	180903
Uninjured (<50 rad)	186	432	2474634

Sample 22

Y = 1000 kt
h.o.b. = 300 m
MLOP = 4 psi
MIOP = 2 psi
IPF = 10

Blast / Radiation	Fatalities	Injuries	Uninjured
Fatal (>450 rad)	639300	2	0
Seriously Ill (200-450 rad)	128083	1	0
Mildly Ill (50-200 rad)	349458	294	1
Uninjured (<50 rad)	1016081	575845	1223260

Sample 23

Y = 1000 kt
h.o.b. = 300 m
MLOP = 10 psi
MIOP = 7 psi
IPF = 10

Blast / Radiation	Fatalities	Injuries	Uninjured
Fatal (>450 rad)	634569	4041	692
Seriously Ill (200-450 rad)	122522	3539	2023
Mildly Ill (50-200 rad)	308434	31738	9582
Uninjured (<50 rad)	274911	292611	2247666

Sample 24

Y = 1000 kt
h.o.b. = 300 m
MLOP = 15 psi
MIOP = 14 psi
IPF = 10

Blast / Radiation	Fatalities	Injuries	Uninjured
Fatal (>450 rad)	630715	1580	7008
Seriously Ill (200-450 rad)	106566	9150	12369
Mildly Ill (50-200 rad)	160471	46740	142542
Uninjured (<50 rad)	18895	15746	2780548

Appendix C

EFFECTS OF ENHANCED RADIATION WEAPONS

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EFFECTS OF ENHANCED RADIATION WEAPONS

During the course of this program, comparative computer runs were made for 5-kt "normal" weapons and 5-kt "radiation-enhanced" weapons. The enhancement factor assumed was 10 . This was applied only to the weapon neutron output.

Figure C-1 shows the blast-only fatalities as a function of MLOP protection for ten weapons exploded at the 10-psi-optimized height of burst. The positions of the weapons were optimized by the ANDANTE program to produce maximum blast-only fatalities for persons in shelters with a 10-psi MLOP.

Also shown on the figure is the total number of fatalities, blast plus radiation-induced, for an enhanced weapon, a normal weapon with no radiation protection, and a normal weapon with a shelter having an initial radiation protection factor of 10.

It is evident from the figure that radiation is the predominant kill mechanism where the blast protection MLOP exceeds about 6 psi. Also evident is that enhancement will increase fatalities by 30 to 100% for the examples shown, or conversely, that a much larger IPF is necessary for protection against enhanced weapons.

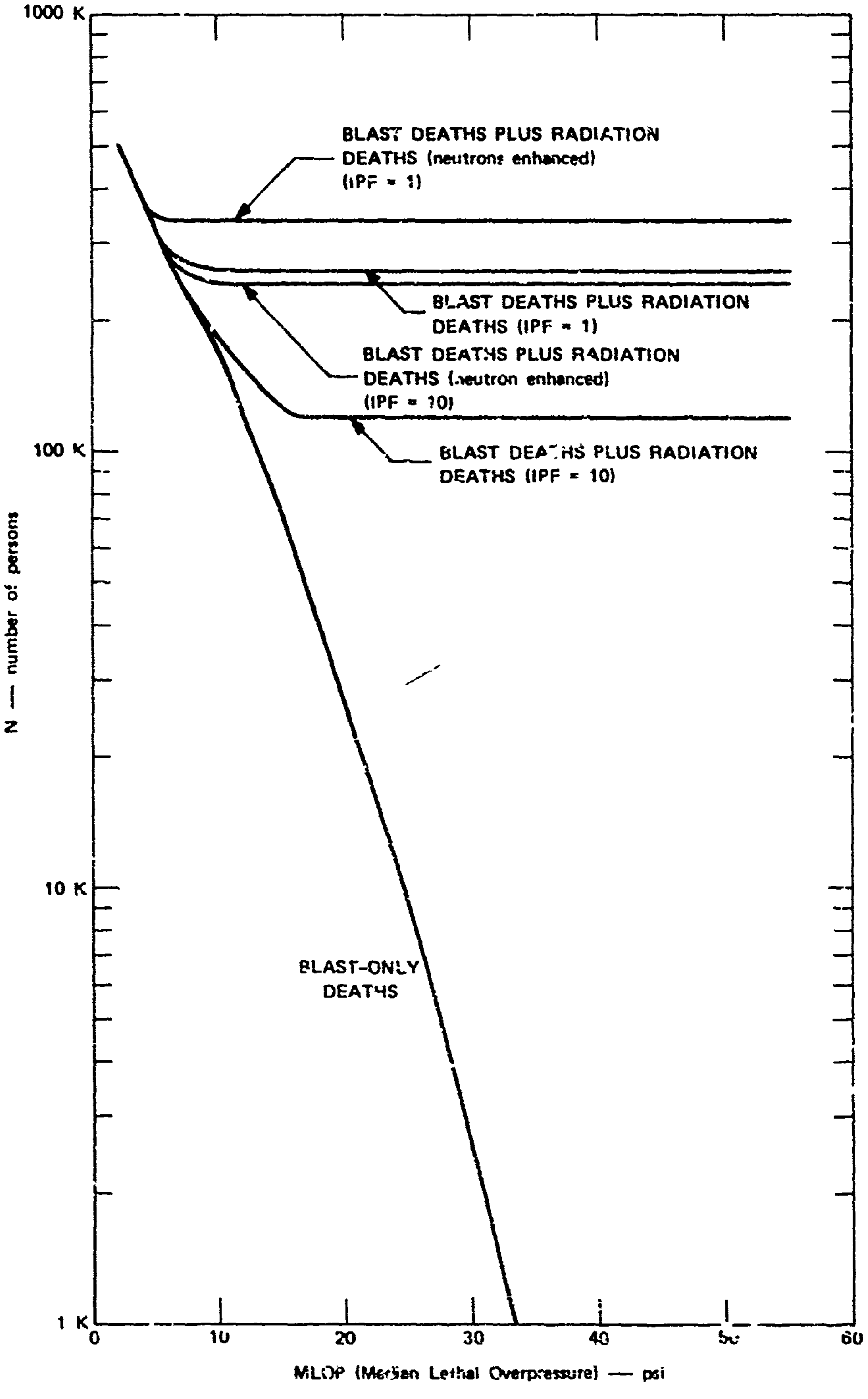

FIGURE C-1 DEATHS vs. MLOP--BLAST-ONLY, RADIATION FOR IPF = 1, IPF = 10, AND FOR ENHANCED NEUTRON OUTPUT

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